Exhibit A

(12) **United States Patent**
Brownrigg et al.

(10) **Patent No.: US 7,054,271 B2**
(45) **Date of Patent: May 30, 2006**

(54) **WIRELESS NETWORK SYSTEM AND METHOD FOR PROVIDING SAME**

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(73) Assignee: **IPCO, LLC**, Atlanta, GA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 175 days.

(21) Appl. No.: **10/386,159**

(22) Filed: **Mar. 10, 2003**

(65) **Prior Publication Data**

US 2004/0062224 A1 Apr. 1, 2004

Related U.S. Application Data

(63) Continuation of application No. 09/492,933, filed on Jan. 27, 2000, now abandoned, which is a continuation of application No. 08/760,895, filed on Dec. 6, 1996, now Pat. No. 6,044,062.

(51) **Int. Cl.**
H04J 1/16 (2006.01)

(52) **U.S. Cl.** **370/238**; 370/254; 370/310; 370/400; 370/465

(58) **Field of Classification Search** 370/237, 370/238, 254–256, 310, 315, 320, 327, 328, 370/338, 351, 501, 400, 465
See application file for complete search history.

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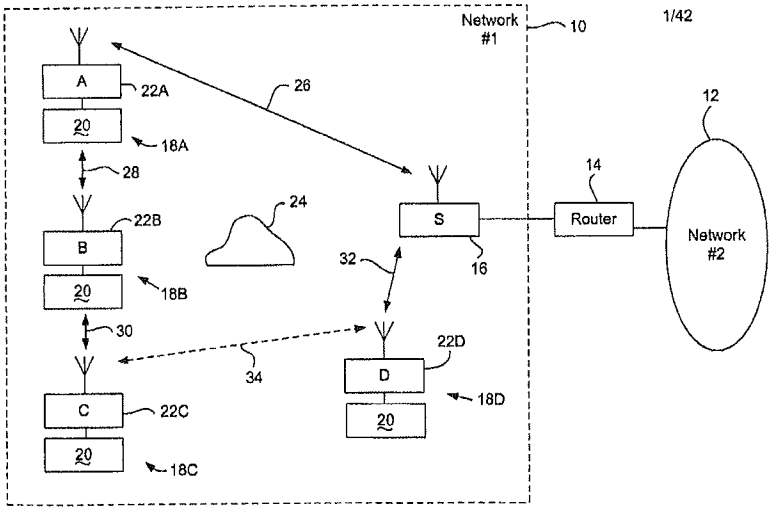
Assistant Examiner—Daniel Ryman

(74) *Attorney, Agent, or Firm*—Joel S. Goldman, Esq

(57) **ABSTRACT**

A wireless network, which includes a wireless router client operable to broadcast data packets to at least one wireless server and one additional wireless client. Each client and server includes programs for determining optimum routes between them. The client also includes a program for determining if a received data packet is not addressed to it and if the packet has been sent via a new optimal route unknown to the client, and for notifying the respective server of such a new optimal route.

12 Claims, 42 Drawing Sheets



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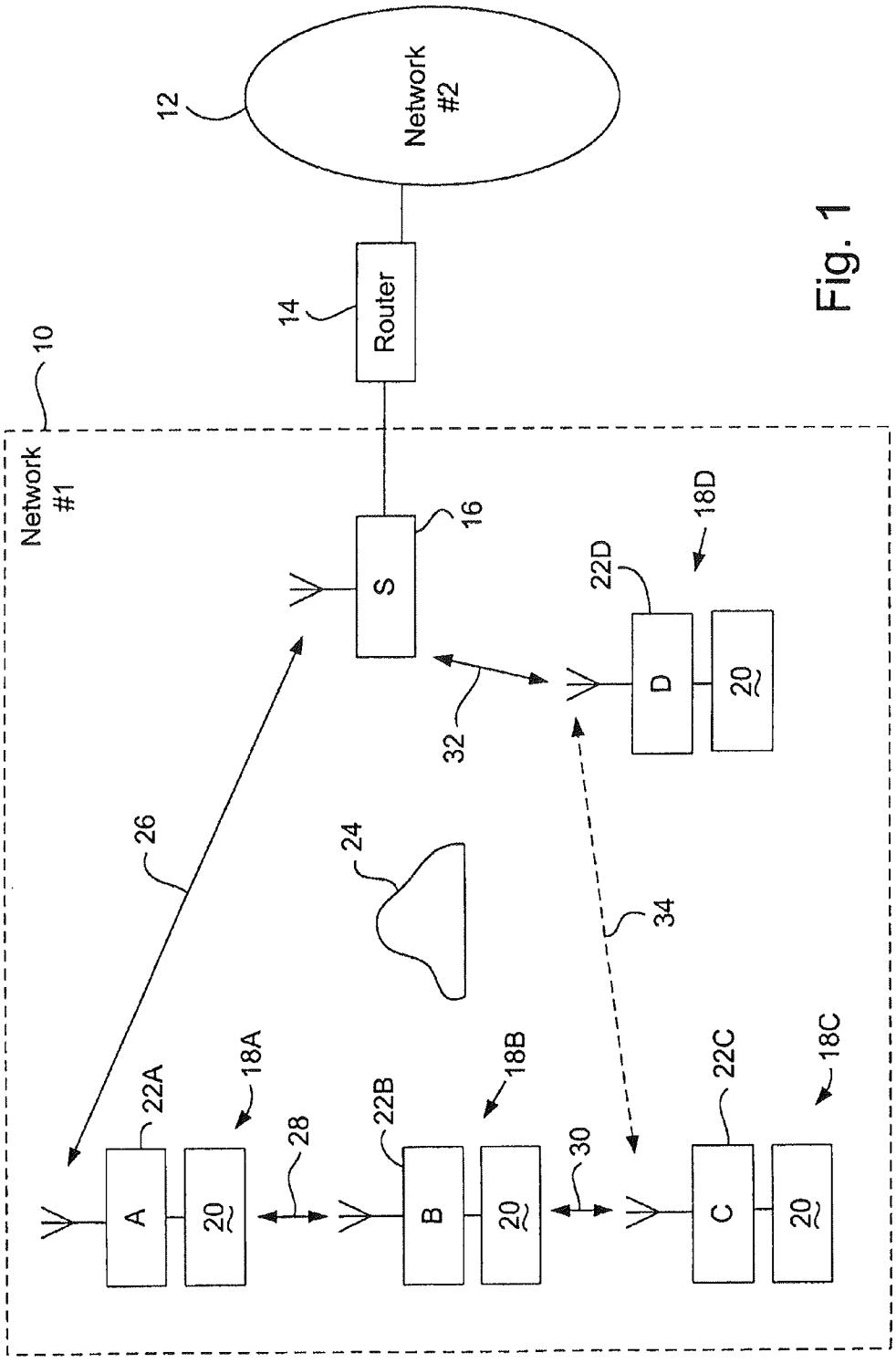

12
Network #2
14
Router
10
Network #1
16
S
18D
22D
D
20
32
26
24
34
18A
22A
A
20
28
22B
18B
B
20
30
22C
18C
C
20

Fig. 1

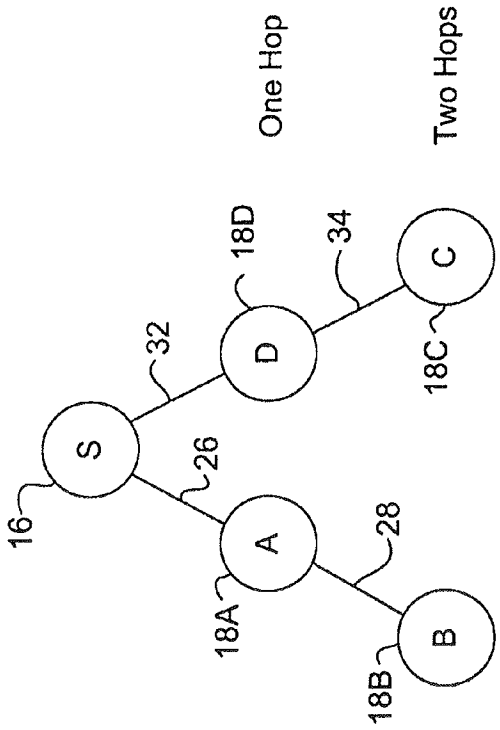

One Hop
Two Hops
16
S
32
D
18D
34
C
18C
26
A
18A
28
B
18B

Fig. 1b

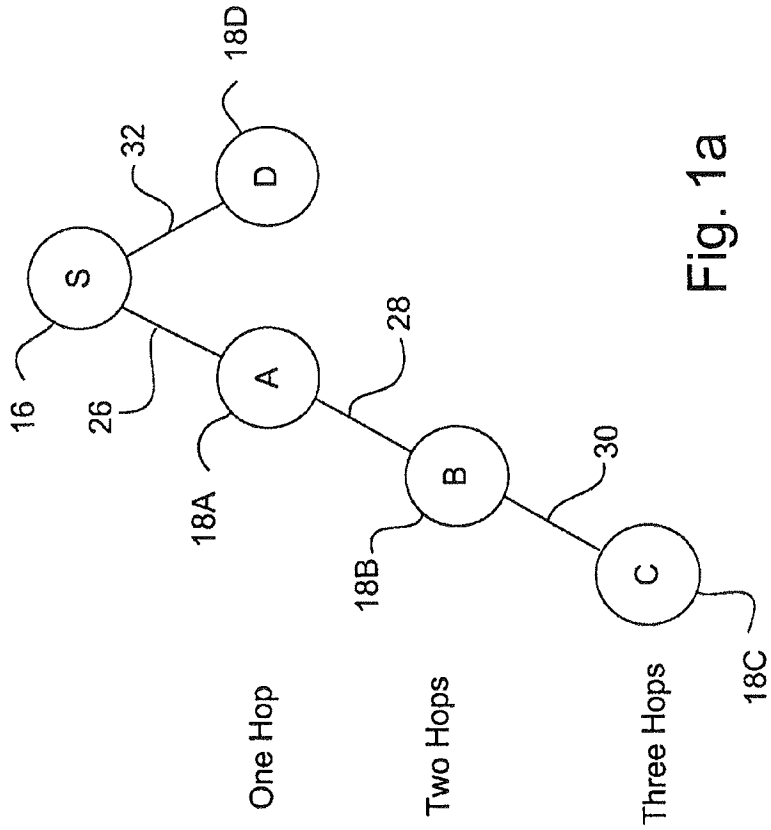

16
S
32
D
18D
26
A
18A
28
B
18B
30
C
18C
One Hop
Two Hops
Three Hops

Fig. 1a

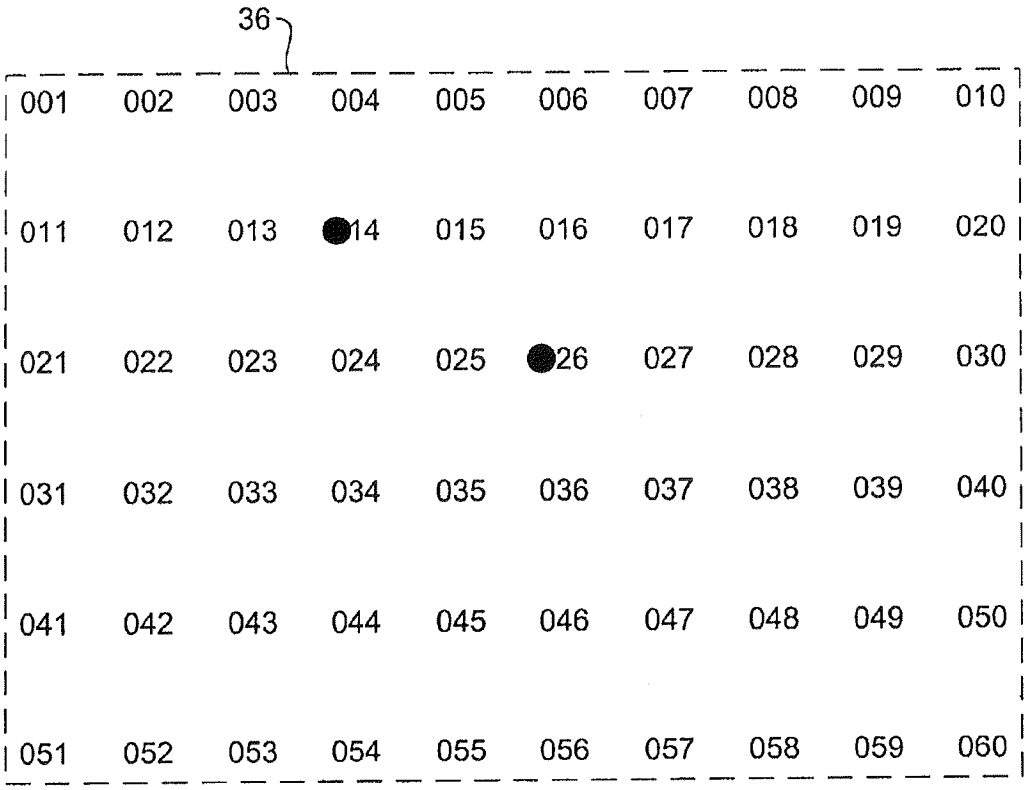
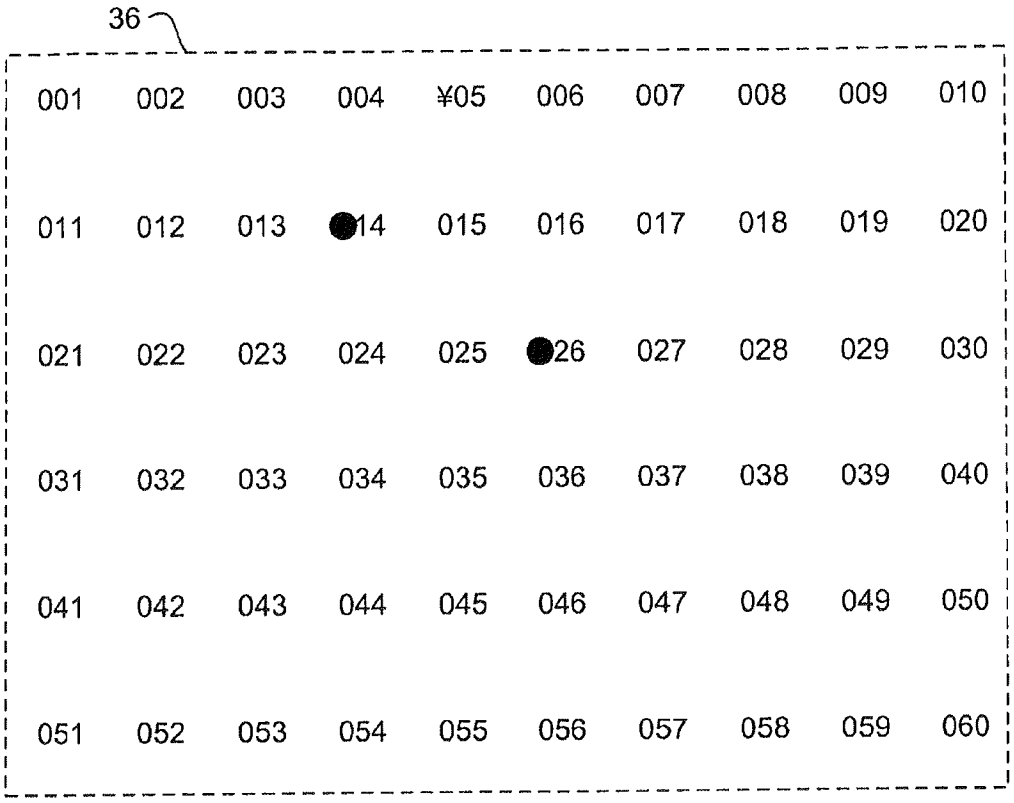

36
001 002 003 004 005 006 007 008 009 010
011 012 013 014 015 016 017 018 019 020
021 022 023 024 025 026 027 028 029 030
031 032 033 034 035 036 037 038 039 040
041 042 043 044 045 046 047 048 049 050
051 052 053 054 055 056 057 058 059 060

Fig. 2a



There is only one Internet server in range of client 5.

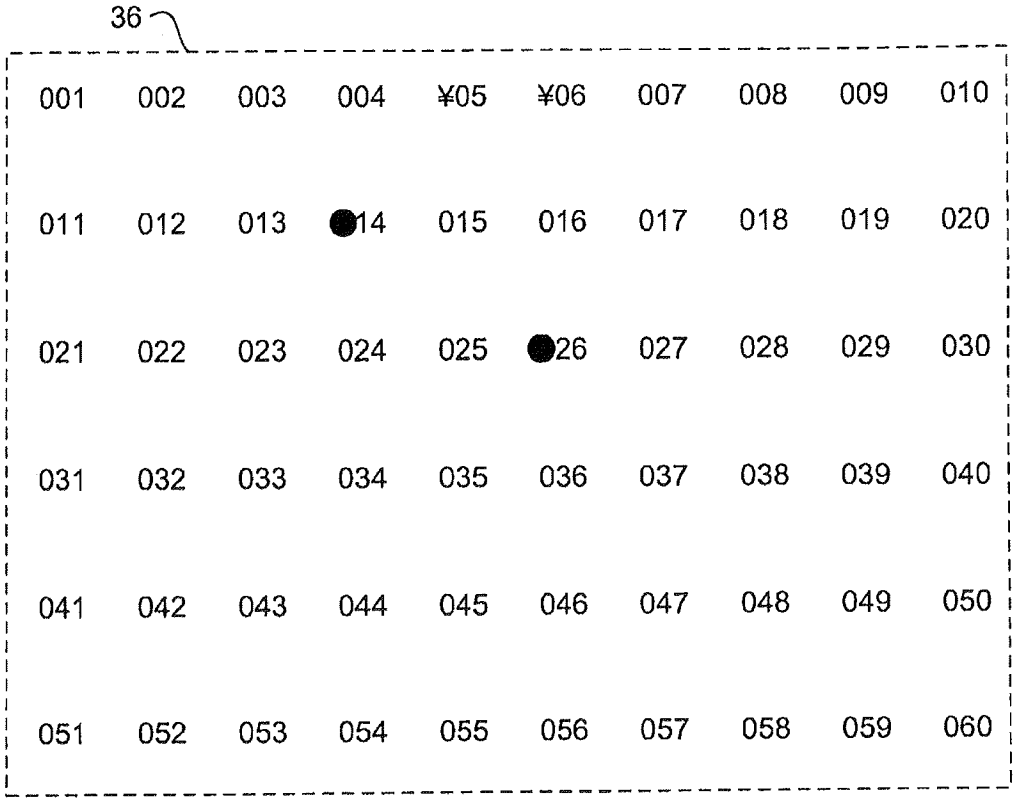
5 will issue an "I am alive" packet seeking a route to the Internet.

Internet server 14 will respond and add user client 5 to its routing table as its left son.

The updated routing table of Internet server 14 is: 14(05).

The route from user client 5 to the Internet is: 05>14.

Fig. 2b



There is only one user client in range of client 6.

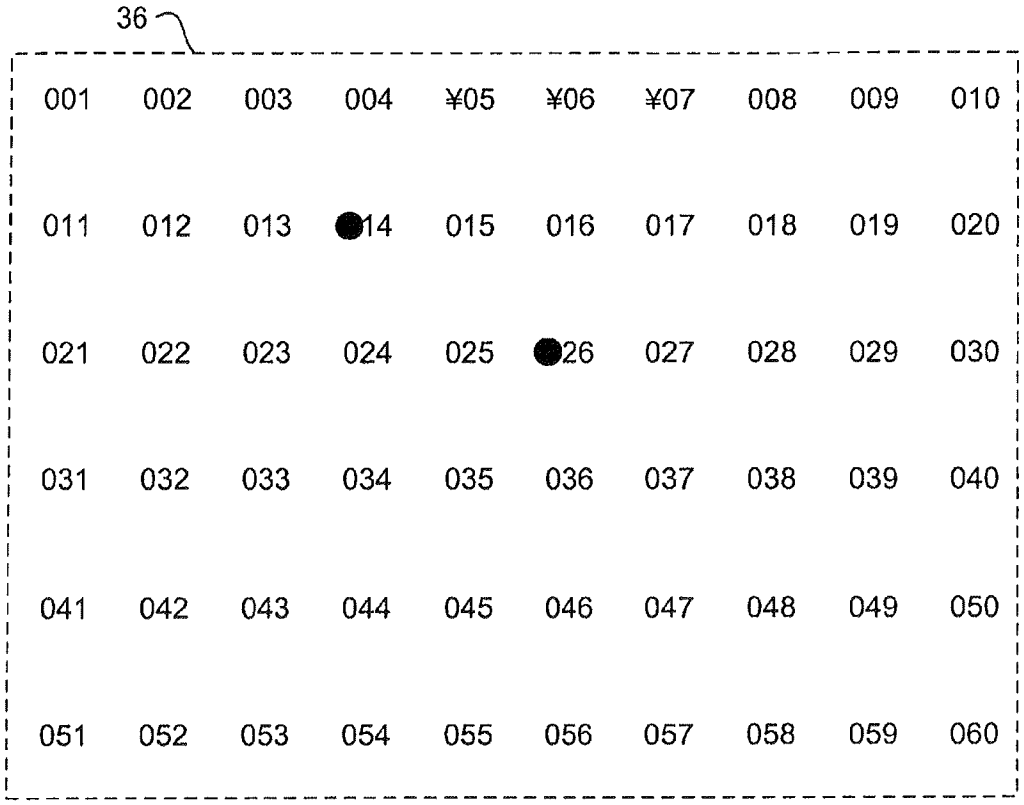
6 will issue an "I am alive" packet seeking a client repeater route to the Internet.

5 will respond and add 6 to its routing table as its left son.

The updated routing table of Internet server 14 is: 14(05(06)).

The route from user client 6 to the Internet is: 06>05>14.

Fig. 2c



There is only one user client in range of client 7.

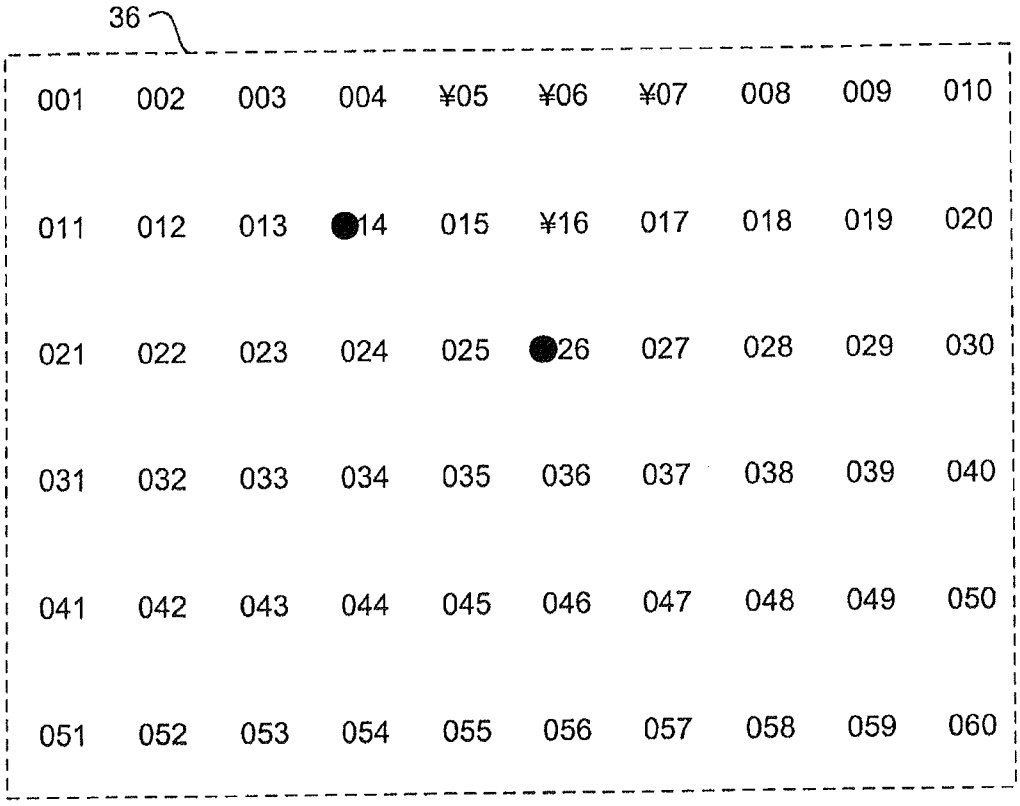
7 will issue an "I am alive" packet seeking a client repeater route to the Internet.

6 will respond and add 7 to its routing table as its left son.

The updated routing table of Internet server 14 is: 14(05(06(07))).

The route from user client 7 to the Internet is: 07>06>05>14.

Fig. 2d



There is only one Internet server in range of client 16.

16 will issue an "I am alive" packet seeking a route to the Internet.

Internet server 26 will respond and add user client 16 to its routing table as its left son.

The updated routing table of Internet server 26 is: 26(16).

The route from user client 16 to the Internet is: 16>26.

Fig. 2e

Server 14 = 14(05(06))
Server 26 = 26(16(07))

Client 05 = 05(06); >14
Client 06 = 06; >05>14
Client 07 = 07; >16>26
Client 16 = 16(07); >26

In a universe of 6 nodes, of which 2 are servers, the average hop distance from a client to an Internet server is 1.5.

Fig. 2f

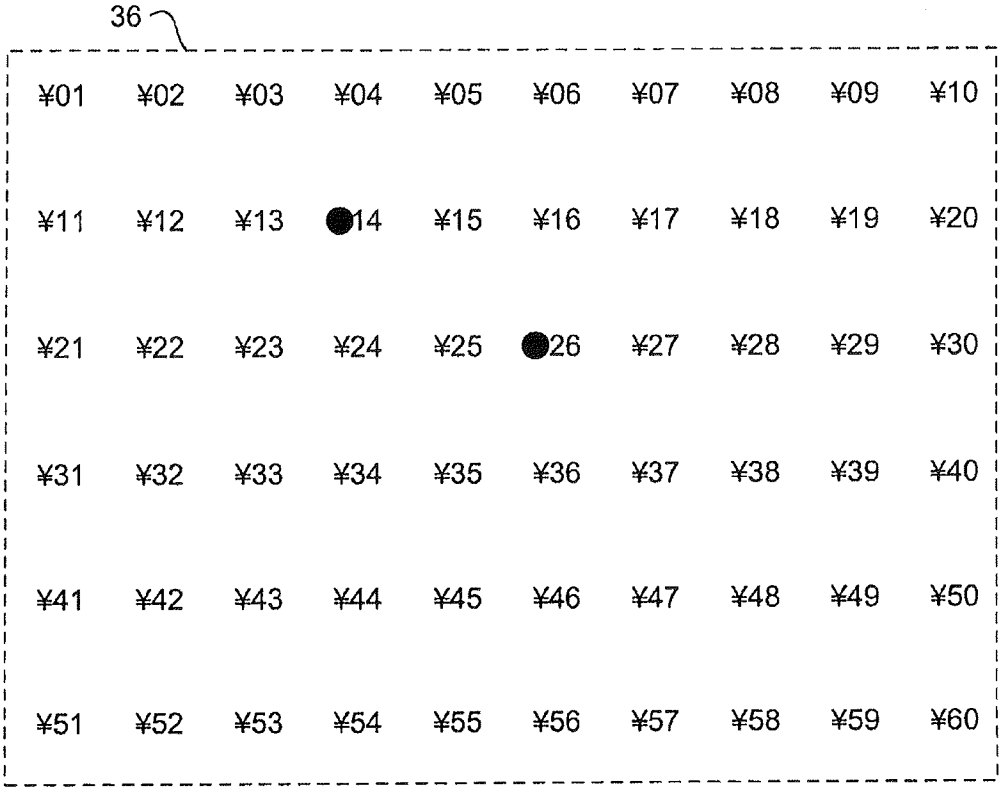

36
¥01 ¥02 ¥03 ¥04 ¥05 ¥06 ¥07 ¥08 ¥09 ¥10
¥11 ¥12 ¥13 ¥14 ¥15 ¥16 ¥17 ¥18 ¥19 ¥20
¥21 ¥22 ¥23 ¥24 ¥25 ¥26 ¥27 ¥28 ¥29 ¥30
¥31 ¥32 ¥33 ¥34 ¥35 ¥36 ¥37 ¥38 ¥39 ¥40
¥41 ¥42 ¥43 ¥44 ¥45 ¥46 ¥47 ¥48 ¥49 ¥50
¥51 ¥52 ¥53 ¥54 ¥55 ¥56 ¥57 ¥58 ¥59 ¥60

Fig. 2g

Server 14 =
14(24(34),23(32(41(51),42(52)),33(43)),13(22(31)),05(06),
04,03(02(11),12(01,21)))

Server 26 =
26(37(48(59(60),49(50),58),38(39(40)),28(29(30)),47(57)),
36(46(56)),35(44(53,54),45(55)),27(18(19(20))),25,
17(08(09(10)),07),16,15)

Client 01 = 01; >12>03>14
Client 02 = 02(11); >03>14
Client 03 = 03(02(11),12(01,21)); >14
Client 04 = 04; >14
Client 05 = 05(06); >14
Client 06 = 06; >05>14
Client 07 = 07; >17>26
Client 08 = 08(09(10)); >17>26
Client 09 = 09(10); >08>17>26
Client 10 = 10; >09>08>17>26
Client 11 = 11; >02>03>14
Client 12 = 12(01,21); >03>14
Client 13 = 13(22(31)); >14
Client 15 = 15; >26
Client 16 = 16; >26
Client 17 = 17(08(09(10)),07); >26
Client 18 = 18(19(20)); >27>26
Client 19 = 19(20); >18>27>26
Client 20 = 20; >19>18>27>26
Client 21 = 21; >12>03>14
Client 22 = 22(31); >13>14
Client 23 = 23(32(41(51),42(52)),33(43)); >14
Client 24 = 24(34); >14
Client 25 = 25; >26
Client 27 = 27(18(19(20))); >26
Client 28 = 28(29(30));>37>26
Client 29 = 29(30);>28>37>26
Client 30 = 30;>29>28>37>26
Client 31 = 31;>22>13>14

Fig. 2h'

Client 32 = 32(41(51),42(52)); >23>14
Client 33 = 33(43);>23>14
Client 34 = 34;>24>14
Client 35 = 35(44(53,54),45(55));>26
Client 36 = 36(46(56));>26
Client 37 = 37(48(59(60),49(50),58),38(39(40)),
28(29(30)),47(57));>26
Client 38 = 38(39(40));>37>26
Client 39 = 39(40);>38>37>26
Client 40 = 40;>39>38>37>26
Client 41 = 41(51);>32>23>14
Client 42 = 42(52);>32>23>14
Client 43 = 43;>33>23>14
Client 44 = 44(53,54);>35>26
Client 45 = 45(55);>35>26
Client 46 = 46(56);>36>26
Client 47 = 47(57);>37>26
Client 48 = 48(59(60),49(50),58);>37>26
Client 49 = 49(50);>48>37>26
Client 50 = 50;>49>48>37>26
Client 51 = 51;>41>32>23>14
Client 52 = 52;>42>32>23>14
Client 53 = 53;>44>35>26
Client 54 = 54;>44>35>26
Client 55 = 55;>45>35>26
Client 56 = 56;>46>36>26
Client 57 = 57;>47>37>26
Client 58 = 58;>48>37>26
Client 59 = 59(60);>48>37>26
Client 60 = 60;>59>48>37>26

In a universe of 60 nodes, of which 2 are servers, the average hop distance from a client to an Internet server is 2.36206897.

Fig. 2h"

Traversing user client universe . . ..

User client, 9, has 5 user client neighbors.

User client, 9, will probe each for the shortest route to the Internet.
9's current route to the Internet is: nonexistant.

9 is now probing 10.
User client, 9, has no Internet server.
9's current route to the Internet is: nonexistant.

9 is now probing 20.
User client, 9, has no Internet server.
9's current route to the Internet is: nonexistant.

9 is now probing 19.
User client, 9, has no Internet server.
9's current route to the Internet is: nonexistant.

9 is now probing 18.
User client, 9, has no Internet server.
9's current route to the Internet is: nonexistant.

9 is now probing 8.
User client 8 will add 9 to its routing table as its left son.

The updated routing table of Internet server 14 is:
14(05(06(07(08(09)))),04,03).

The route from user client 9 to the Internet is:
09>08>07>06>05>14.

Fig. 2i

Traversing user client universe . . ..

User client, 29, has 8 user client neighbors.

User client, 29, will probe each for the shortest route to the Internet.
29's current route to the Internet is: nonexistant.

29 is now probing 19.
User client 19 will add 29 to its routing table as its left son.

The updated routing table of Internet server 14 is:
14(24,23,13,05(06(07(08(18(28),09(19(29),10(20))))))),
04,03(12(22,21))).

The route from user client 29 to the Internet is:
29>19>09>08>07>06>05>14.

Fig. 2j

Traversing user client universe . . ..

User client, 7, has 5 user client neighbors.

User client, 7, will probe each for the shortest route to the Internet.
7's current route to the Internet is: 07>06>05>14.

7 is now probing 8.
7's current route to the Internet is: 07>06>05>14.

7 is now probing 18.
7's current route to the Internet is: 07>06>05>14.

7 is now probing 17.
User client, 7, has probed its neighbor, user client, 17, and found a shorter path to the Internet.

The old routing table of Internet server, 14, is:
14(24(34(44(54))),23(33(43(53))),13,05(06(07(08(18(28(38(48(58)))),
09(19(29(39(49(59)))),10(20(30(40(50(60))))))))),04,03(02,12(01,
22(32(42(52))),21(31(41(51)))))).

The updated routing table of Internet server, 26, is:
26(37(47(57)),36(46(56)),35(45(55)),27,25,17(07(08(18(28(38
(48(58)))),09(19(29(39(49(59)))),10(20(30(40(50(60))))))))),16,15).

The route from user client, 7, to the Internet is: 07>17>26.
7's current route to the Internet is: 07>17>26.

7 is now probing 16.
7's current route to the Internet is: 07>17>26.

7 is now probing 6.
7's final route is 07>17>26.

Fig. 2k

Traversing user client universe . . ..

User client, 8, has 5 user client neighbors.

User client, 8, will probe each for the shortest route to the Internet.
8's current route to the Internet is: 08>07>17>26.

8 is now probing 9.
8's current route to the Internet is: 08>07>17>26.

8 is now probing 19.
8's current route to the Internet is: 08>07>17>26.

8 is now probing 18.
8's current route to the Internet is: 08>07>17>26.

8 is now probing 17.
User client, 8, has probed its neighbor, user client, 17, and found a shorter path to the Internet.

The old routing table of Internet server, 26, is:
26(37(47(57)),36(46(56)),35(45(55)),27,25,17(07(08(18(28(38(48(58)))),09(19(29(39(49(59)))),10(20(30(40(50(60)))))))),16,15).

The updated routing table of Internet server, 26, is:
26(37(47(57)),36(46(56)),35(45(55)),27,25,17(08(18(28(38(48(58)))),09(19(29(39(49(59)))),10(20(30(40(50(60)))))),07),16,15).

The route from user client, 8, to the Internet is: 08>17>26.
8's current route to the Internet is: 08>17>26.

8 is now probing 7.
8's final route is 08>17>26.

Fig. 2I

Traversing user client universe . . ..

User client, 18, has 8 user client neighbors.

User client, 18, will probe each for the shortest route to the Internet.
18's current route to the Internet is: 18>08>17>26.

18 is now probing 8.
18's current route to the Internet is: 18>08>17>26.

18 is now probing 9.
18's current route to the Internet is: 18>08>17>26.

18 is now probing 19.
18's current route to the Internet is: 18>08>17>26.

18 is now probing 29.
18's current route to the Internet is: 18>08>17>26.

18 is now probing 28.
18's current route to the Internet is: 18>08>17>26.

18 is now probing 27.
User client, 18, has probed its neighbor, user client, 27, and found a shorter path to the Internet.
The old routing table of Internet server, 26, is:
26(37(47(57)),36(46(56)),35(45(55)),27,25,17(08(18(28(38(48(58)))),09(19(29(39(49(59)))),10(20(30(40(50(60)))))),07),16,15).

The updated routing table of Internet server, 26, is:
26(37(47(57)),36(46(56)),35(45(55)),27(18(28(38(48(58))))),25,17(08(09(19(29(39(49(59)))),10(20(30(40(50(60)))))),07),16,15).

The route from user client, 18, to the Internet is: 18>27>26.
18's current route to the Internet is: 18>27>26.

18 is now probing . . ..

18's final route is 18>27>26.

Fig. 2m

User client, 29, has 8 user client neighbors.

User client, 29, will probe each for the shortest route to the Internet.
29's current route to the Internet is: 29>19>18>27>26.

29 is now probing 19.
29's current route to the Internet is: 29>19>18>27>26.

29 is now probing 20.
29's current route to the Internet is: 29>19>18>27>26.

29 is now probing 30.
29's current route to the Internet is: 29>19>18>27>26.

29 is now probing 40.
29's current route to the Internet is: 29>19>18>27>26.

29 is now probing 39.
29's current route to the Internet is: 29>19>18>27>26.

29 is now probing 38.
29's current route to the Internet is: 29>19>18>27>26.

29 is now probing 28.
User client, 29, has probed its neighbor, user client, 28, and found a shorter path to the Internet.
The old routing table of Internet server, 26, is:
26(37(28(38(48(58))),47(57)),36(46(56)),35(45(55)),27(18(19(20(30(40(50(60)))),29(39(49(59)))))),25,17(08(09(10)),07),16,15).

The updated routing table of Internet server, 26, is:
26(37(28(29(39(49(59))),38(48(58))),47(57)),36(46(56)),35(45(55)),27(18(19(20(30(40(50(60))))))),25,17(08(09(10)),07),16,15).

The route from user client, 29, to the Internet is: 29>28>37>26.
29's current route to the Internet is: 29>28>37>26.

29 is now probing 18.
29's final route is 29>28>37>26.

Fig. 2n

Traversing user client universe . . ..

User client, 44, has 8 user client neighbors.

User client, 44, will probe each for the shortest route to the Internet.
44's current route to the Internet is: 44>34>24>14.

44 is now probing 34.
44's current route to the Internet is: 44>34>24>14.

44 is now probing 35.
User client, 44, has probed its neighbor, user client, 35, and found a shorter path to the Internet.
The old routing table of Internet server, 14, is:
14(24(34(44(54))),23(32(41(51),42(52)),33(43(53))),13(22(31)),05(06),04,03(02,12(01(11),21))).

The updated routing table of Internet server, 14, is:
14(24(34),23(32(41(51),42(52)),33(43(53))),13(22(31)),05(06),04,03(02,12(01(11),21))).

The updated routing table of Internet server, 26, is:
26(37(38(39(40(50(60)),49(59)),48(58)),28(29(30)),47(57)),36(46(56)),35(44(54),45(55)),27(18(19(20))),25,17(08(09(10)),07),16,15).

The route from user client, 44, to the Internet is: 44>35>26.
44's current route to the Internet is: 44>28>37>26.

44 is now probing . . .
.
.
.
44's final route is 44>35>26.

Fig. 2o

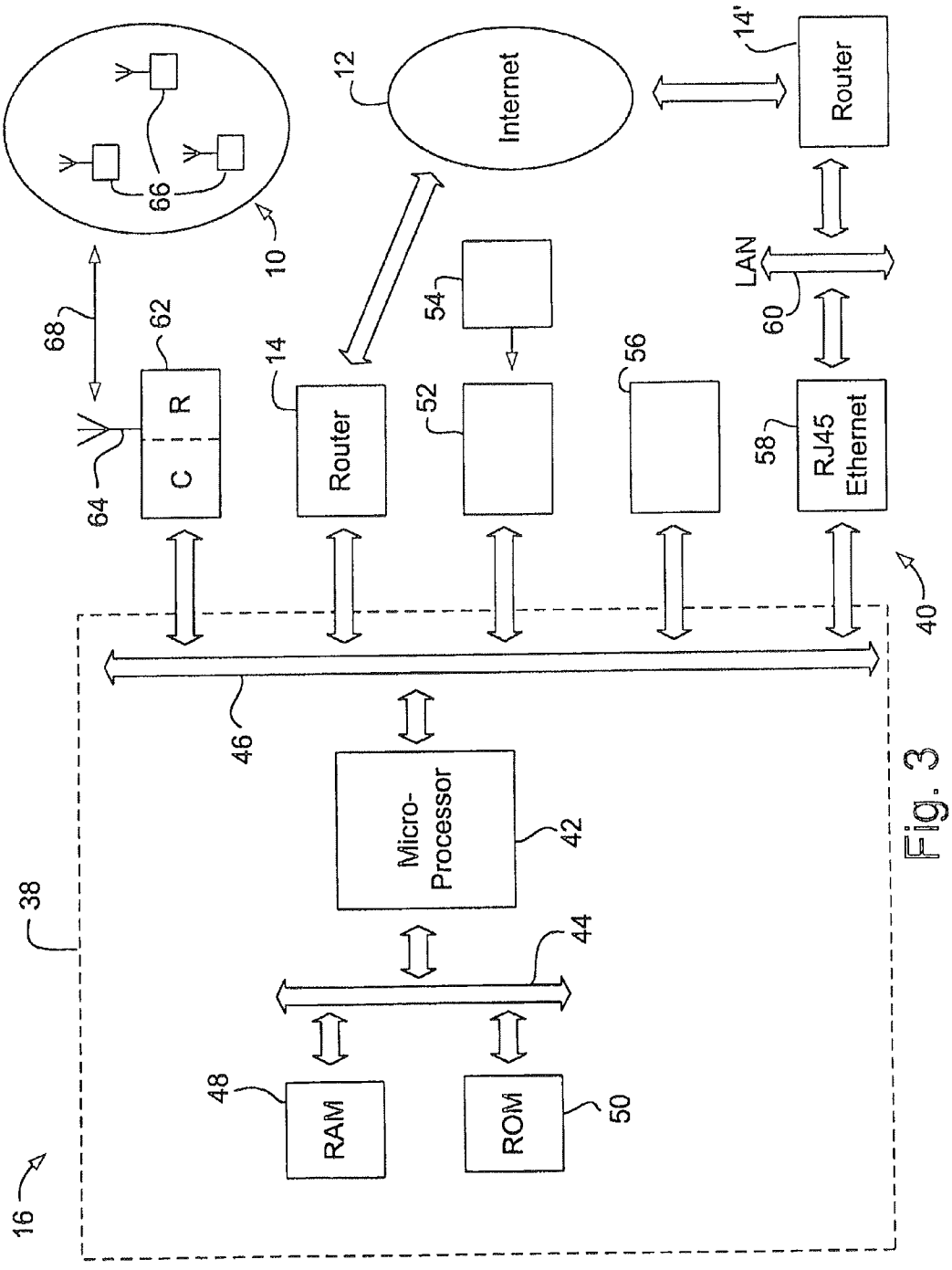

Internet
12
14'
Router
10
66
68
62
R
C
64
14
Router
54
52
56
LAN
60
58
RJ45 Ethernet
40
46
Micro-Processor
42
38
44
48
RAM
ROM
50
16

Fig. 3

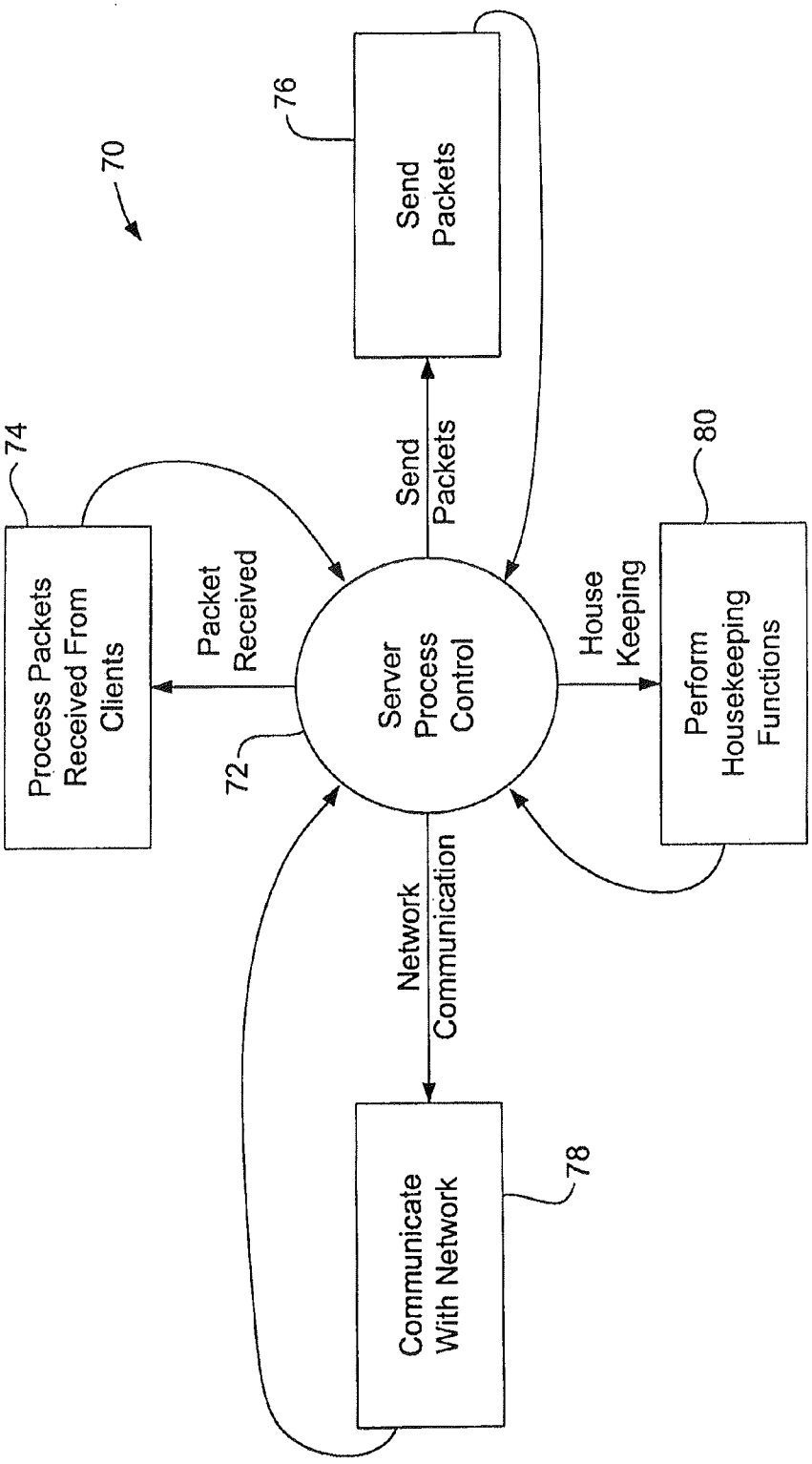

70
76
Send Packets
74
Process Packets Received From Clients
Packet Received
Server Process Control
72
Send Packets
House Keeping
80
Perform Housekeeping Functions
Network Communication
Communicate With Network
78

Fig. 4

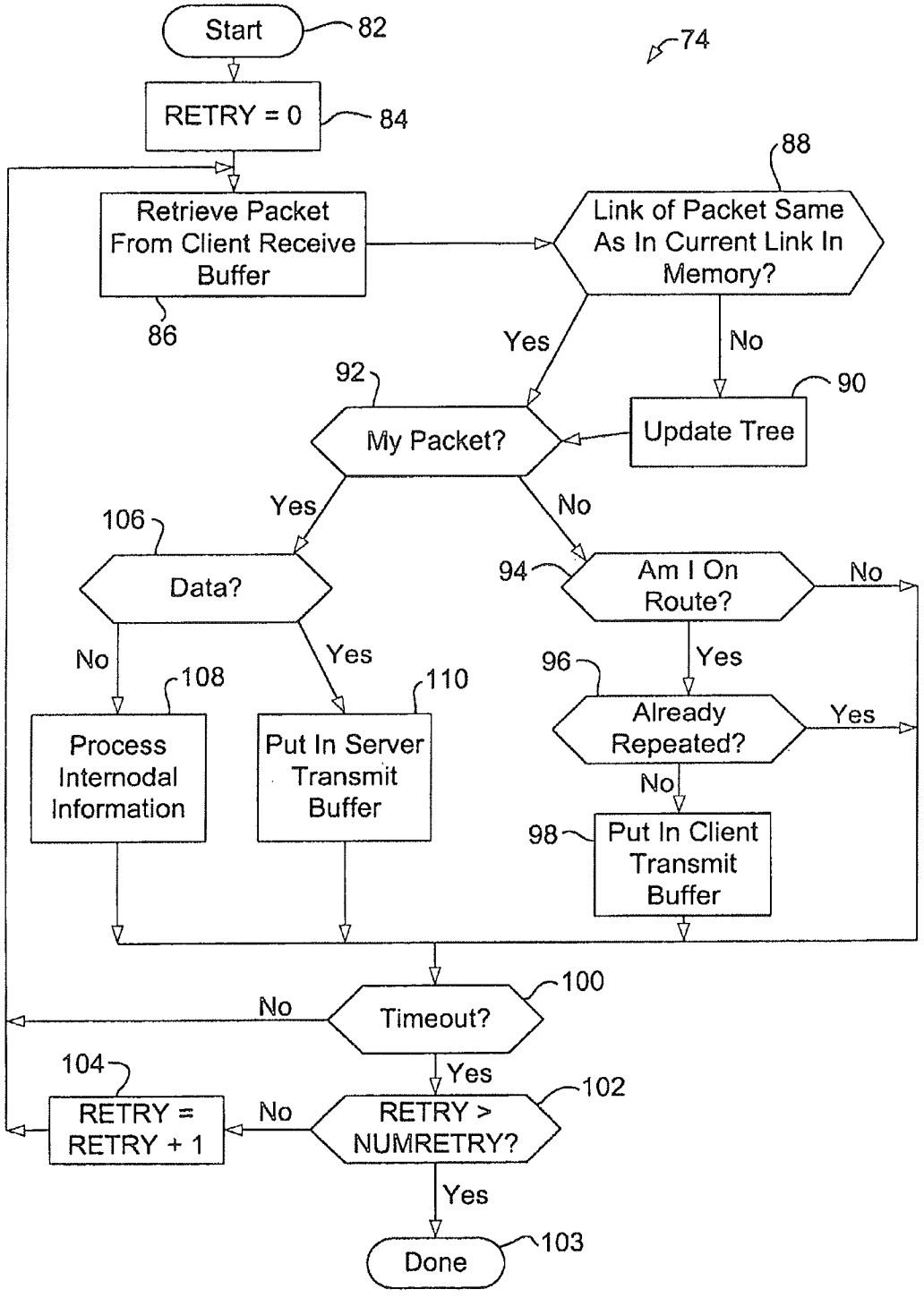

Start
82
74
RETRY = 0
84
88
Retrieve Packet From Client Receive Buffer
Link of Packet Same As In Current Link In Memory?
86
Yes
No
92
90
My Packet?
Update Tree
Yes
No
106
Data?
94
Am I On Route?
No
No
Yes
Yes
96
108
110
Already Repeated?
Yes
Process Internodal Information
Put In Server Transmit Buffer
No
98
Put In Client Transmit Buffer
100
No
Timeout?
104
Yes
102
RETRY = RETRY + 1
No
RETRY > NUMRETRY?
Yes
103
Done

Fig. 5

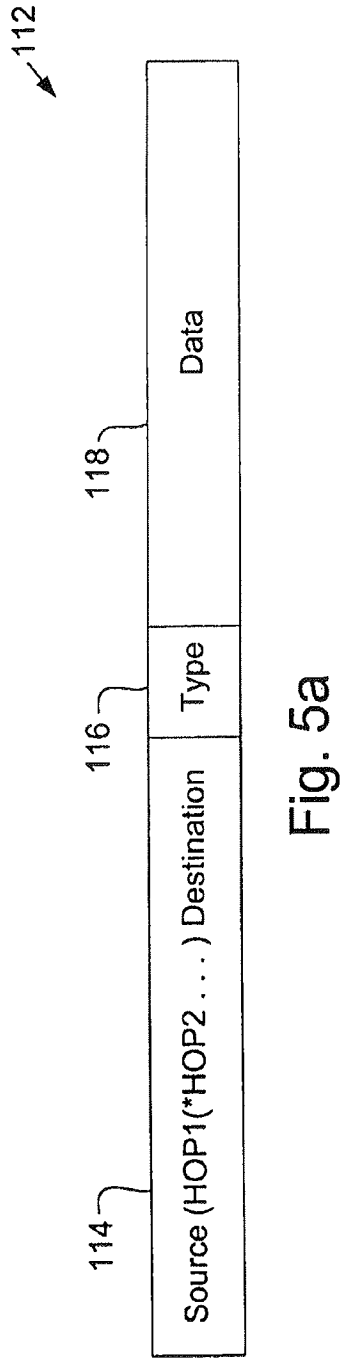


Fig. 5a

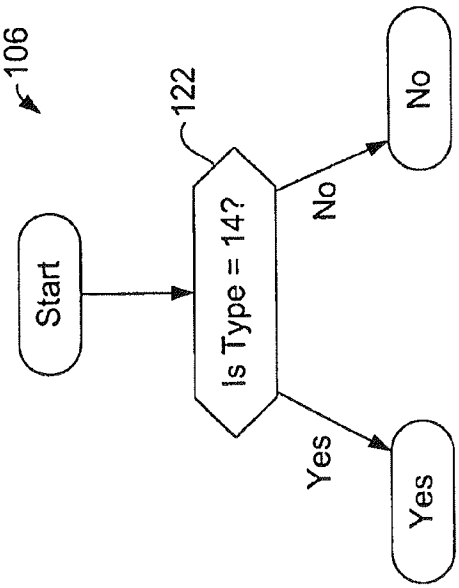


Fig. 5c

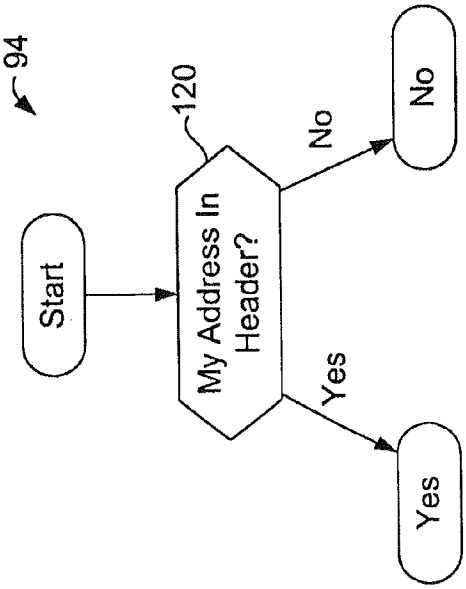


Fig. 5b

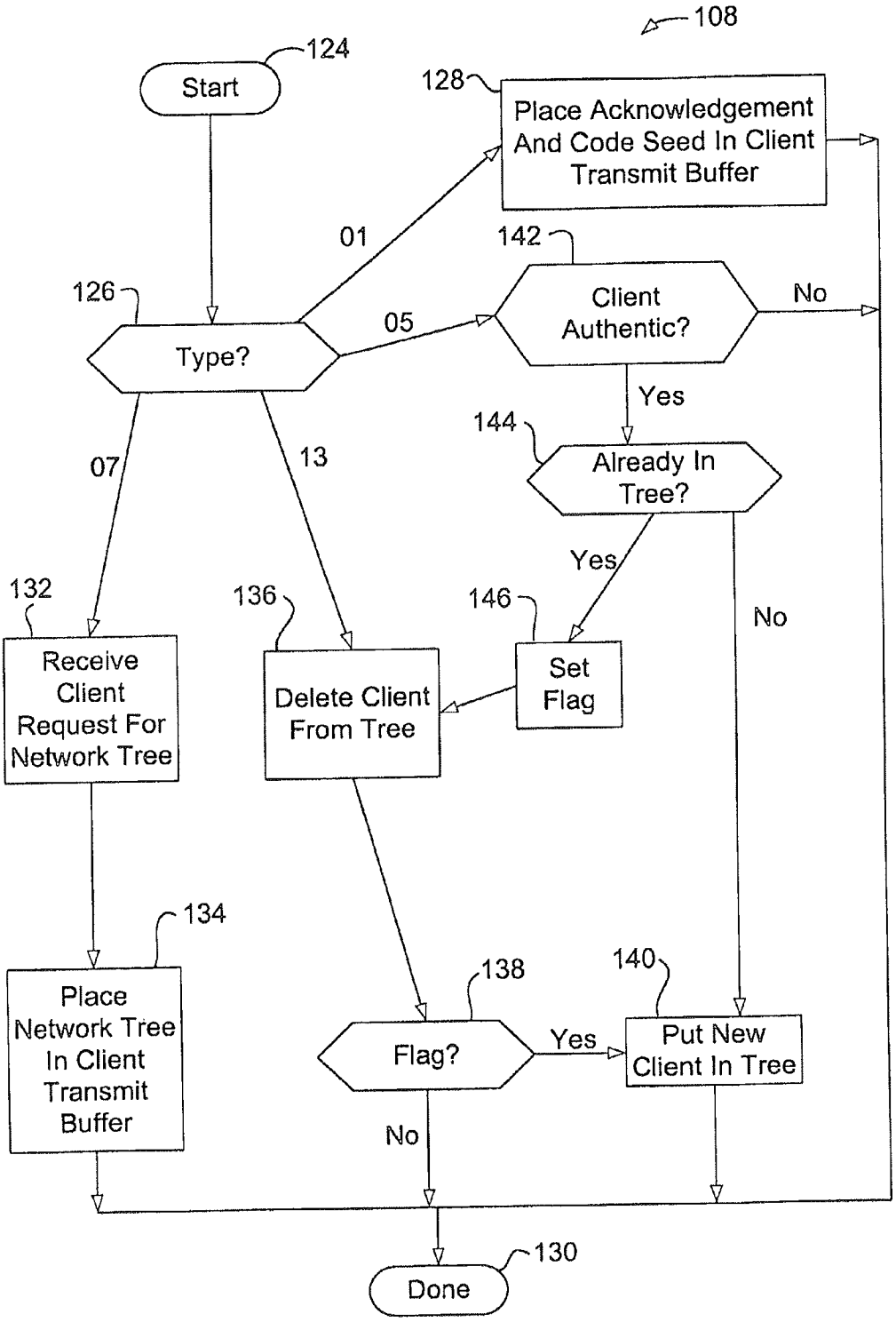

108
124
Start
128
Place Acknowledgement And Code Seed In Client Transmit Buffer
01
142
126
Client Authentic?
No
Type?
05
Yes
144
07
13
Already In Tree?
Yes
132
136
146
No
Receive Client Request For Network Tree
Delete Client From Tree
Set Flag
134
138
140
Place Network Tree In Client Transmit Buffer
Flag?
Yes
Put New Client In Tree
No
130
Done

Fig. 6

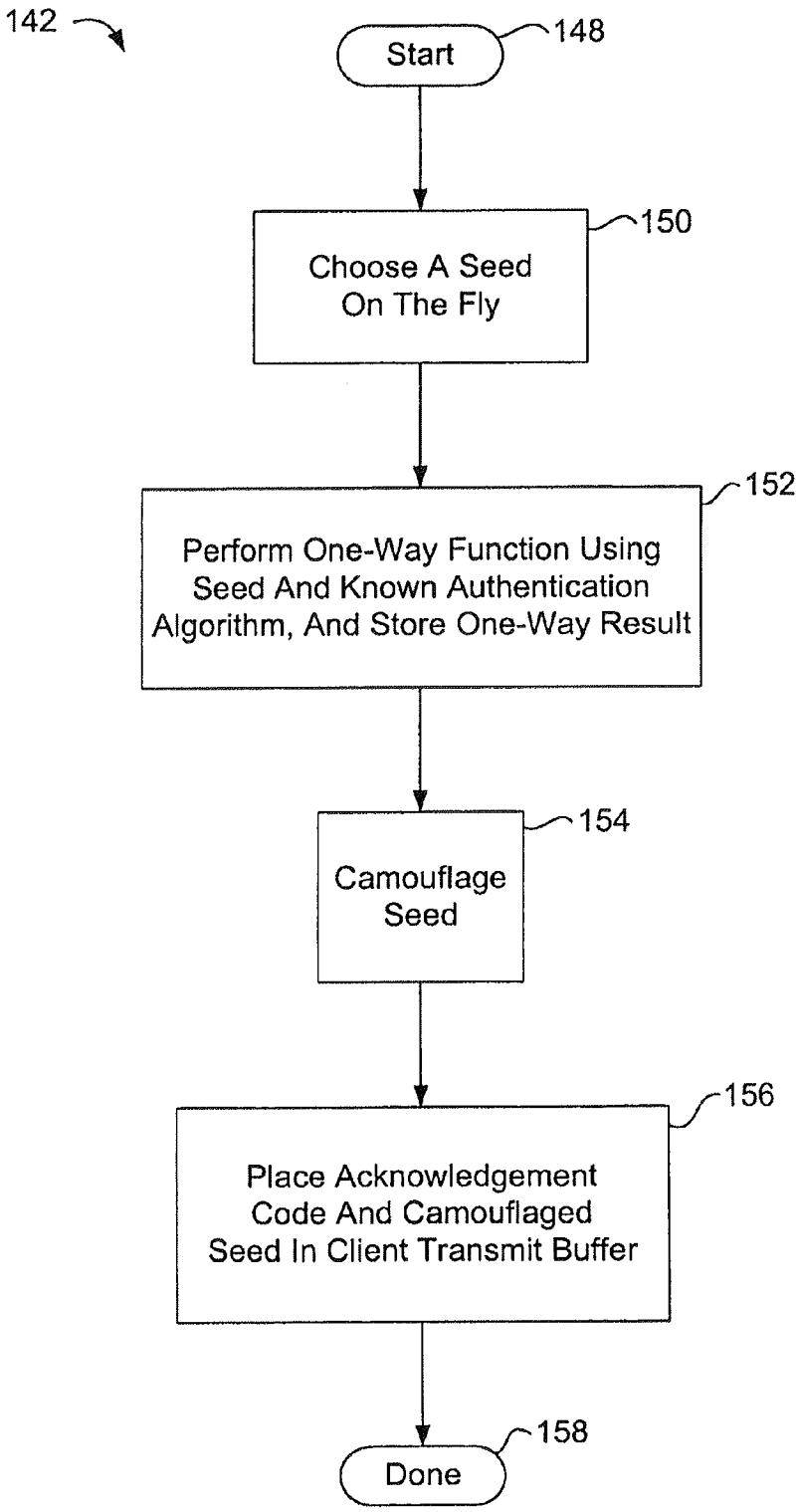

142
Start
148
Choose A Seed On The Fly
150
Perform One-Way Function Using Seed And Known Authentication Algorithm, And Store One-Way Result
152
Camouflage Seed
154
Place Acknowledgement Code And Camouflaged Seed In Client Transmit Buffer
156
Done
158

Fig. 6a

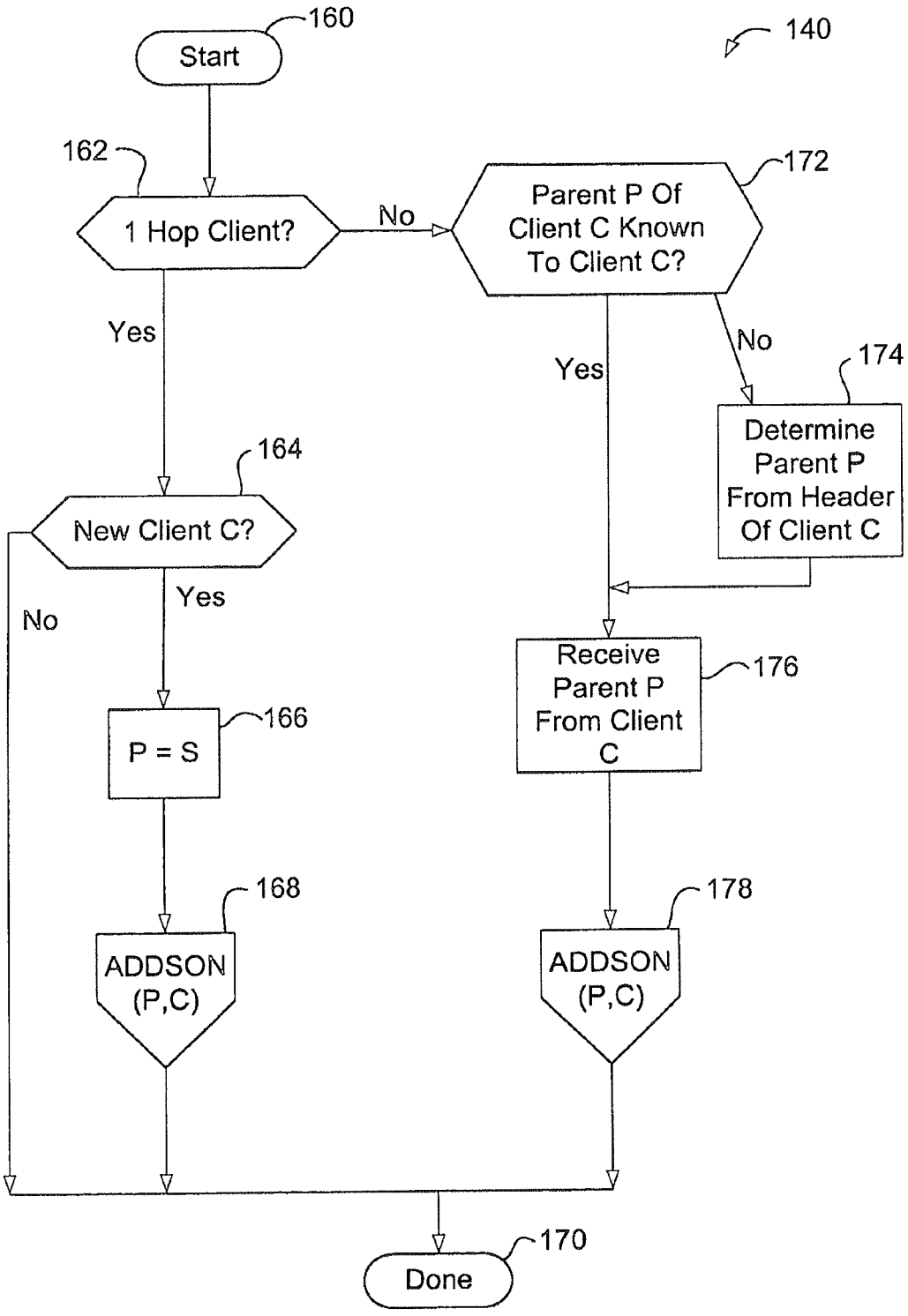

160
Start
140
162
1 Hop Client?
No
172
Parent P Of Client C Known To Client C?
Yes
No
Yes
174
Determine Parent P From Header Of Client C
164
New Client C?
Yes
No
Receive Parent P From Client C
176
P = S
166
168
178
ADDSON (P,C)
ADDSON (P,C)
170
Done

Fig. 6b

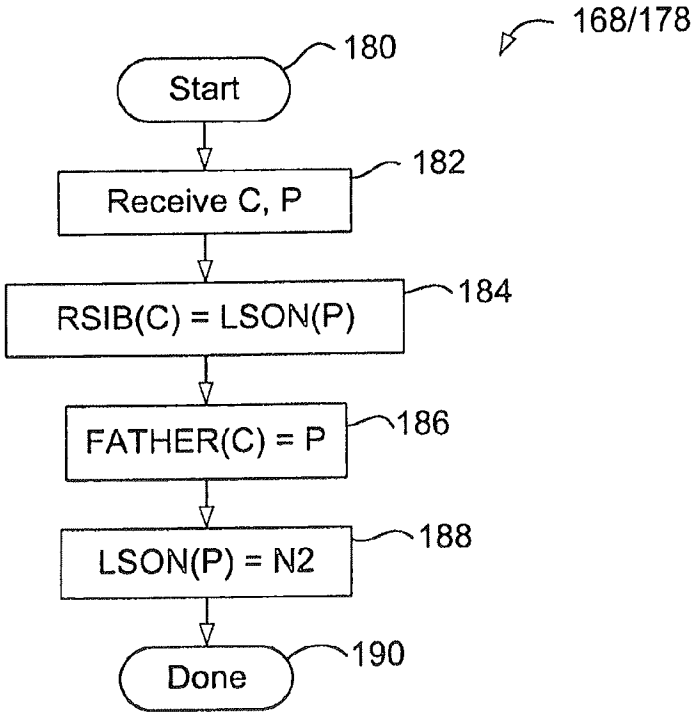


Fig. 7

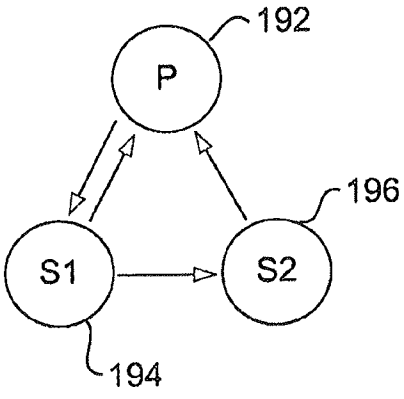


Fig. 7a

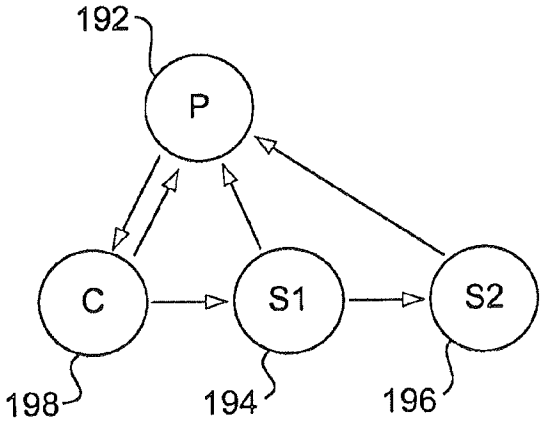


Fig. 7b

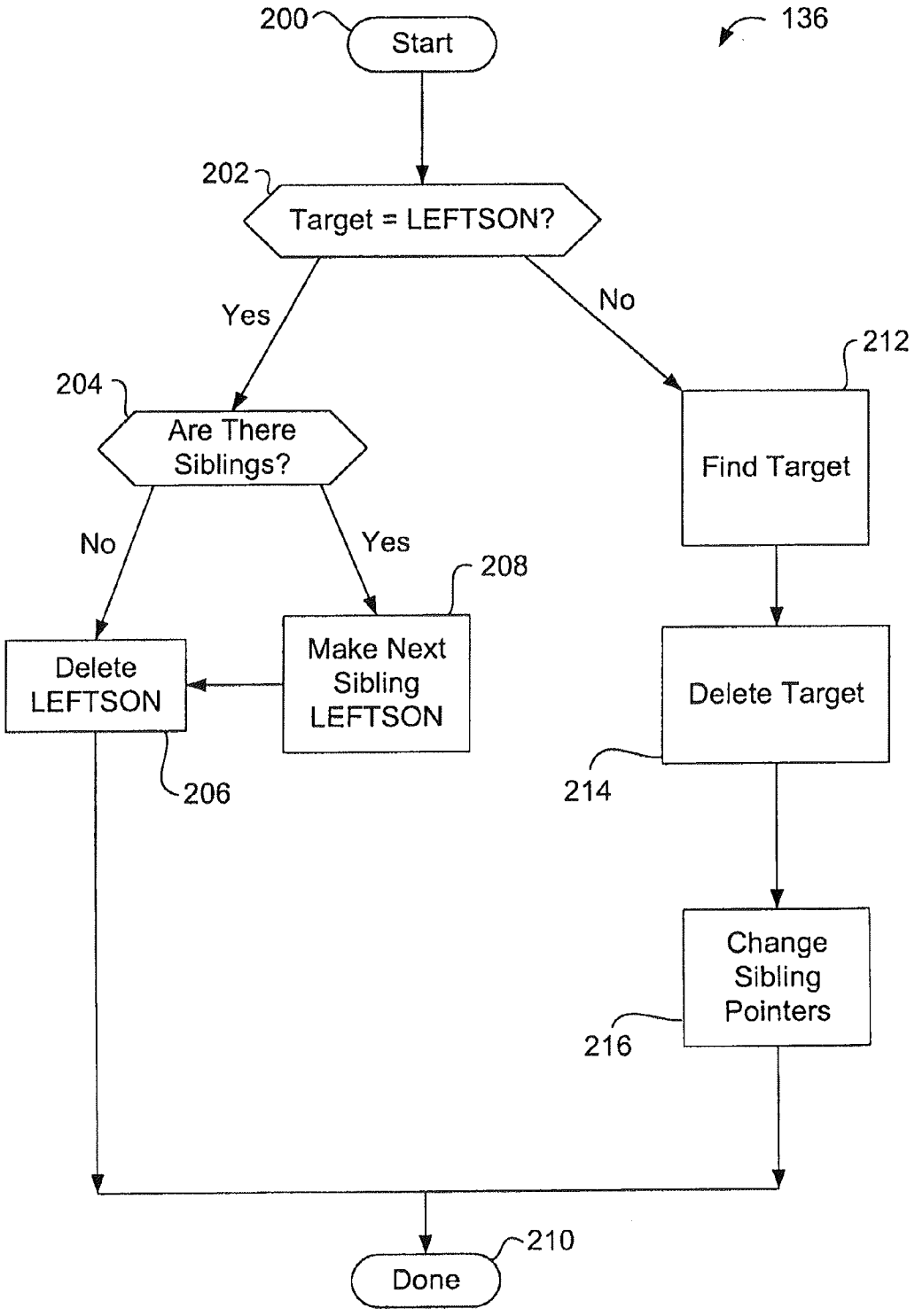

200
Start
136
202
Target = LEFTSON?
Yes
No
212
204
Are There Siblings?
Find Target
No
Yes
208
Delete LEFTSON
Make Next Sibling LEFTSON
Delete Target
206
214
Change Sibling Pointers
216
210
Done

Fig. 8

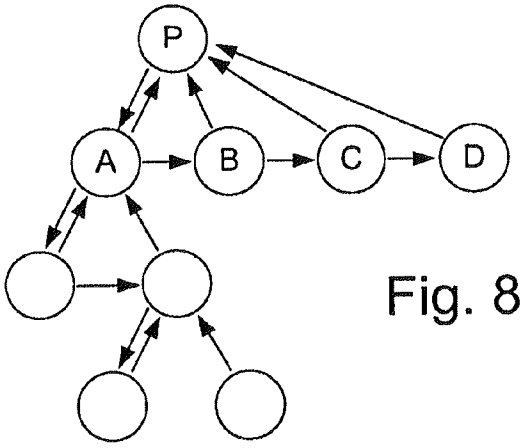


Fig. 8a

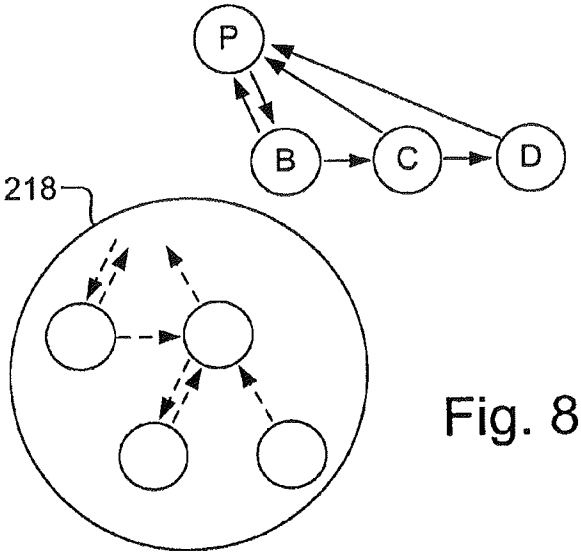


Fig. 8b

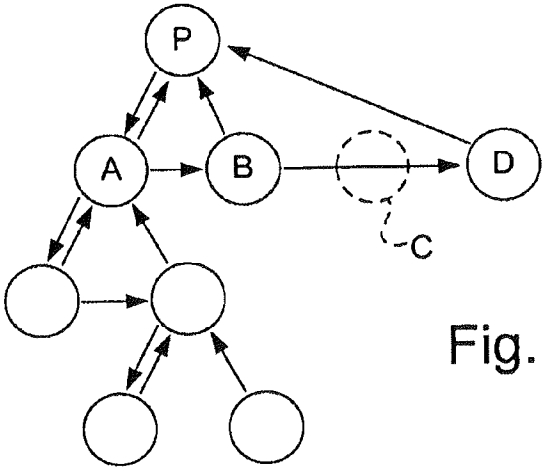


Fig. 8c

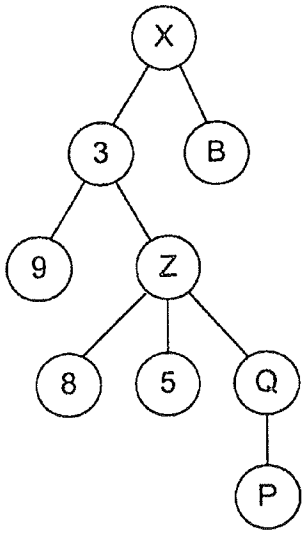


Fig. 9a

X(3(9,Z(8,5,Q(P))),B) 222

Fig. 9b

224 Element	226 Node Name	228 Time Stamp	230 Memory Location Of Node
1	3	1AFG	12FG3
2	P	E013	9AA22
3	X	99F6	.
4	5	B999	.
5	8	B999	.
6	Q	.	.
7	9	.	.
8	B	.	.
9	Z	.	.
.	.	.	.
.	.	.	.
.	.	.	.

Fig. 9c

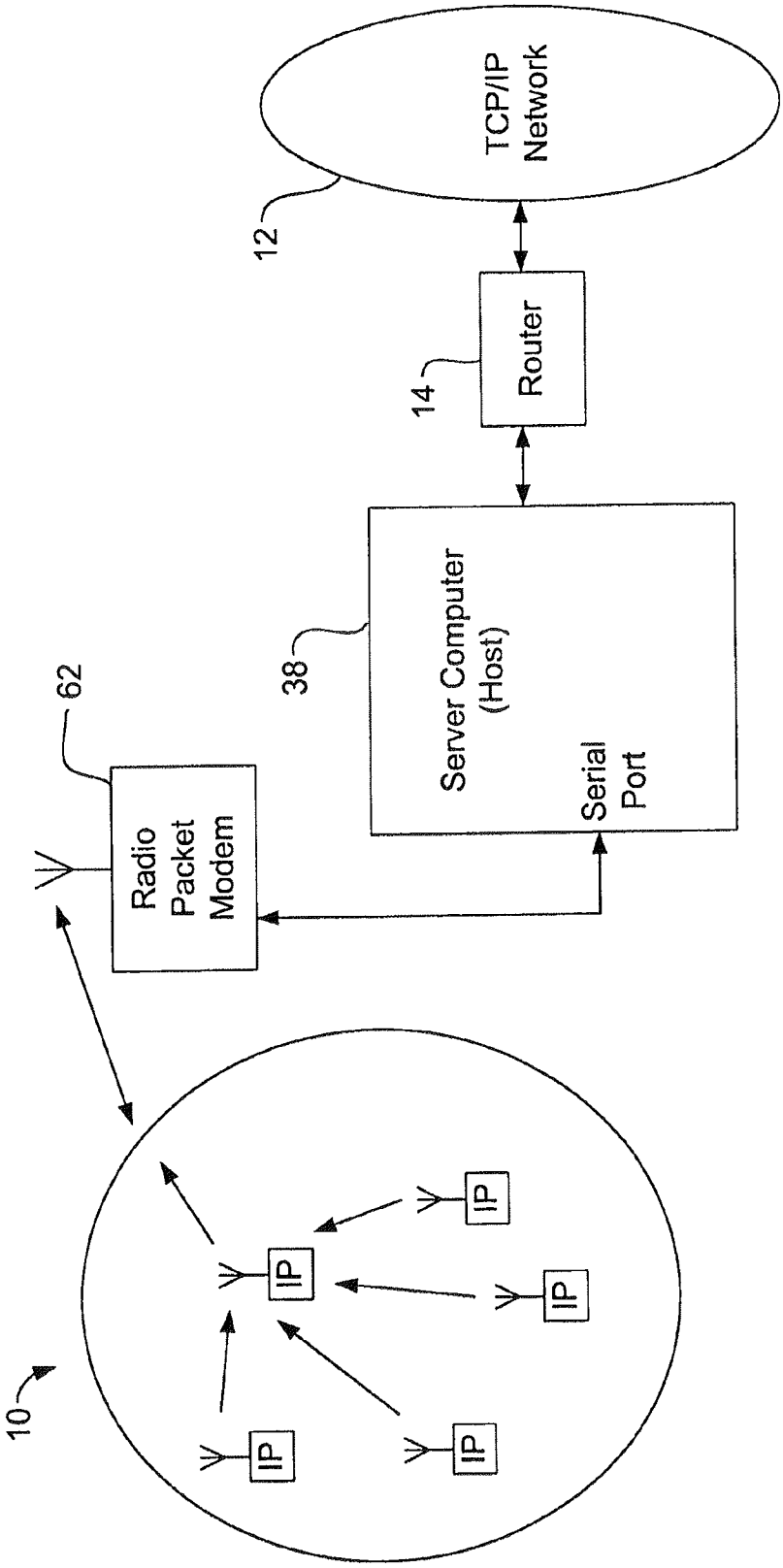

TCP/IP Network
12
Router
14
Server Computer (Host)
38
Serial Port
62
Radio Packet Modem
IP
IP
IP
IP
IP
10

Fig. 10

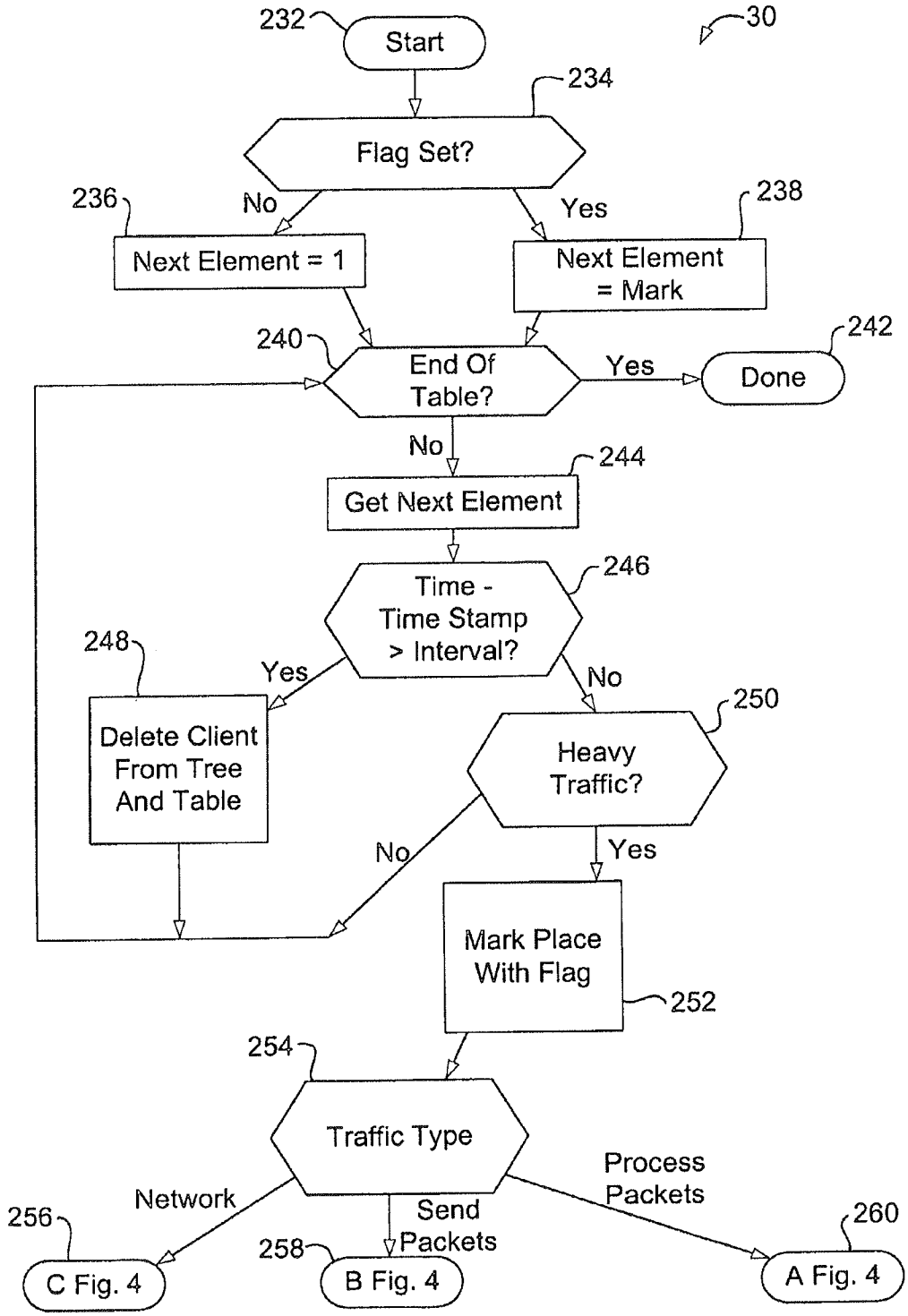

232
Start
30
234
Flag Set?
236
No
Yes
238
Next Element = 1
Next Element = Mark
240
End Of Table?
Yes
242
Done
No
244
Get Next Element
246
Time - Time Stamp > Interval?
248
Yes
No
Delete Client From Tree And Table
250
Heavy Traffic?
No
Yes
Mark Place With Flag
252
254
Traffic Type
Network
Send Packets
Process Packets
256
258
260
C Fig. 4
B Fig. 4
A Fig. 4

Fig. 11

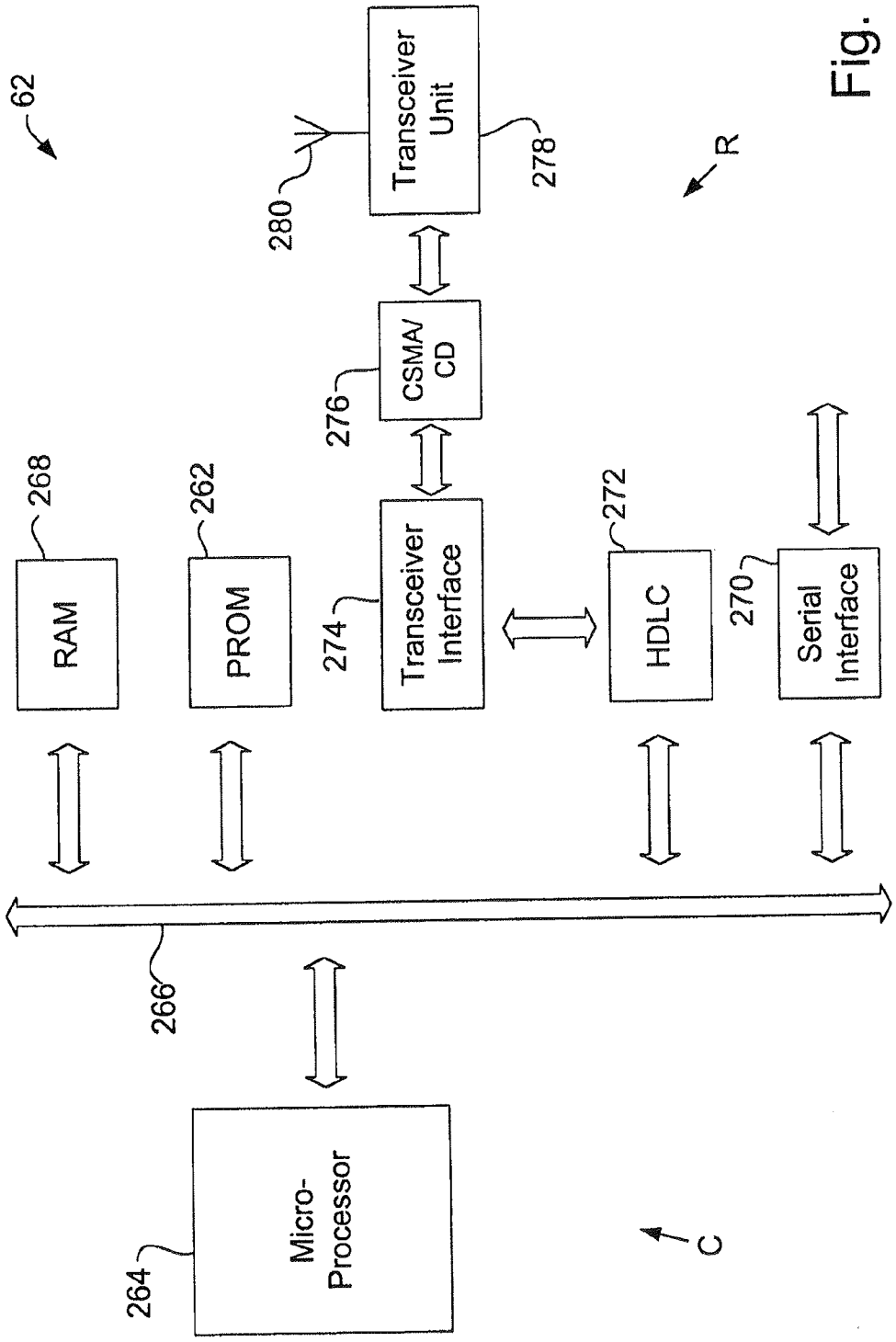

62
Transceiver Unit
278
280
R
CSMA/ CD
276
RAM
268
PROM
262
Transceiver Interface
274
HDLC
272
Serial Interface
270
266
Micro-Processor
264
C

Fig. 12

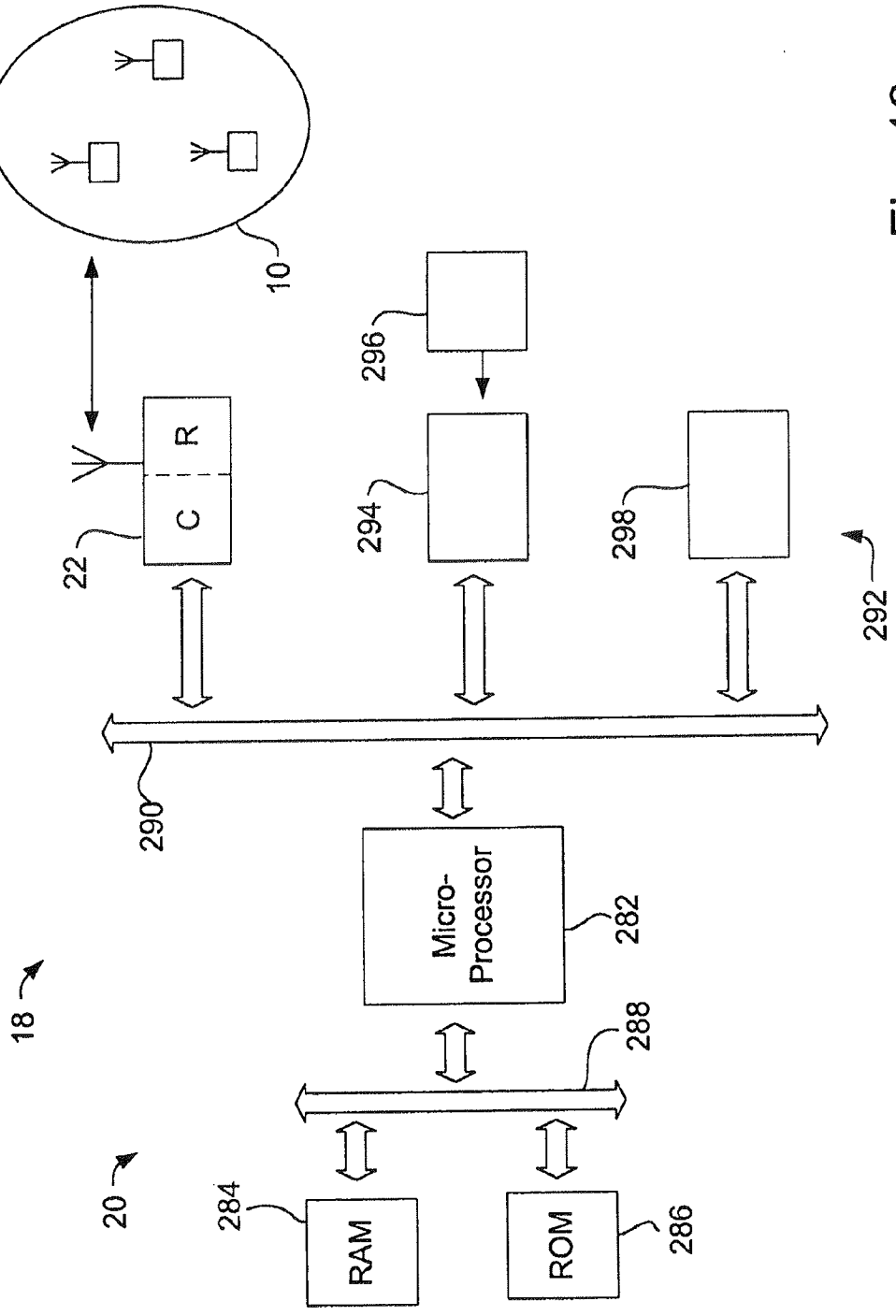

10
296
294
298
R
C
22
292
290
Micro-
Processor
282
18
288
20
284
RAM
ROM
286

Fig. 13

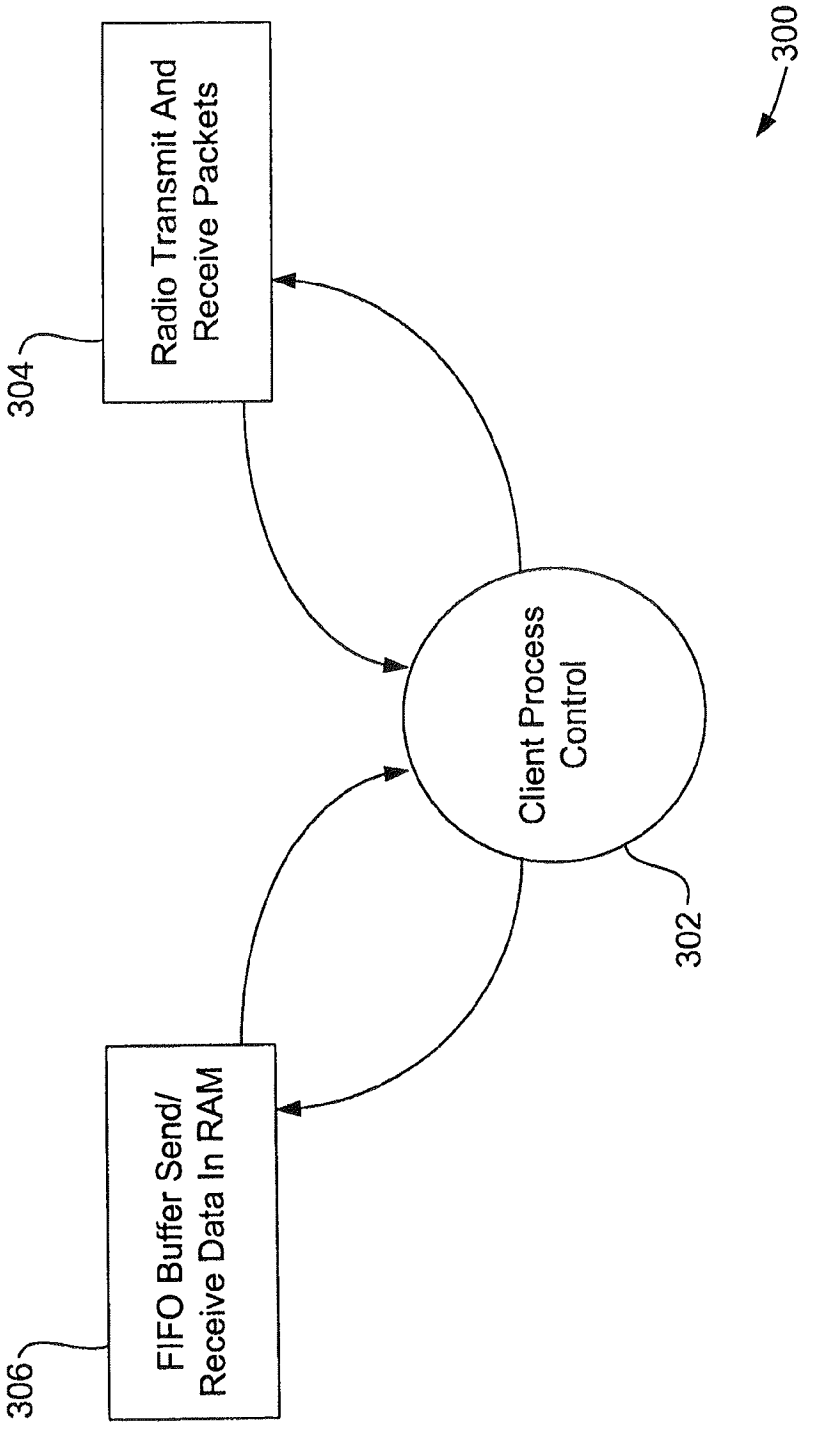

300
Radio Transmit And Receive Packets
304
Client Process Control
302
FIFO Buffer Send/ Receive Data In RAM
306

Fig. 14

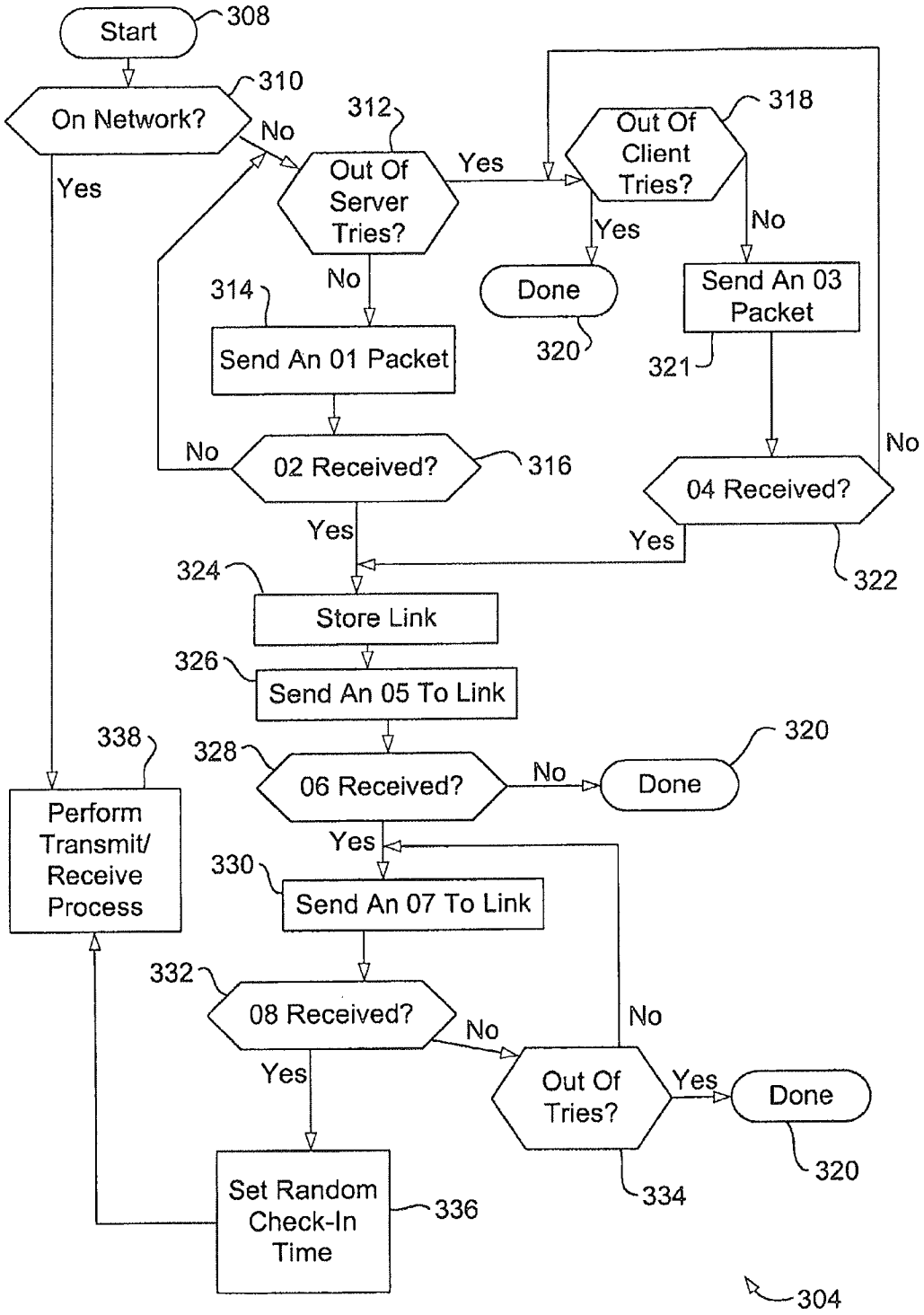

Start
308
On Network?
310
No
Yes
Out Of Server Tries?
312
Yes
No
Out Of Client Tries?
318
Yes
No
Done
320
Send An 03 Packet
321
Send An 01 Packet
314
No
02 Received?
316
No
Yes
04 Received?
No
Yes
322
Store Link
324
Send An 05 To Link
326
Perform Transmit/ Receive Process
338
06 Received?
328
No
Done
320
Yes
Send An 07 To Link
330
08 Received?
332
No
Yes
Out Of Tries?
No
Yes
Done
320
334
Set Random Check-In Time
336
304

Fig. 15

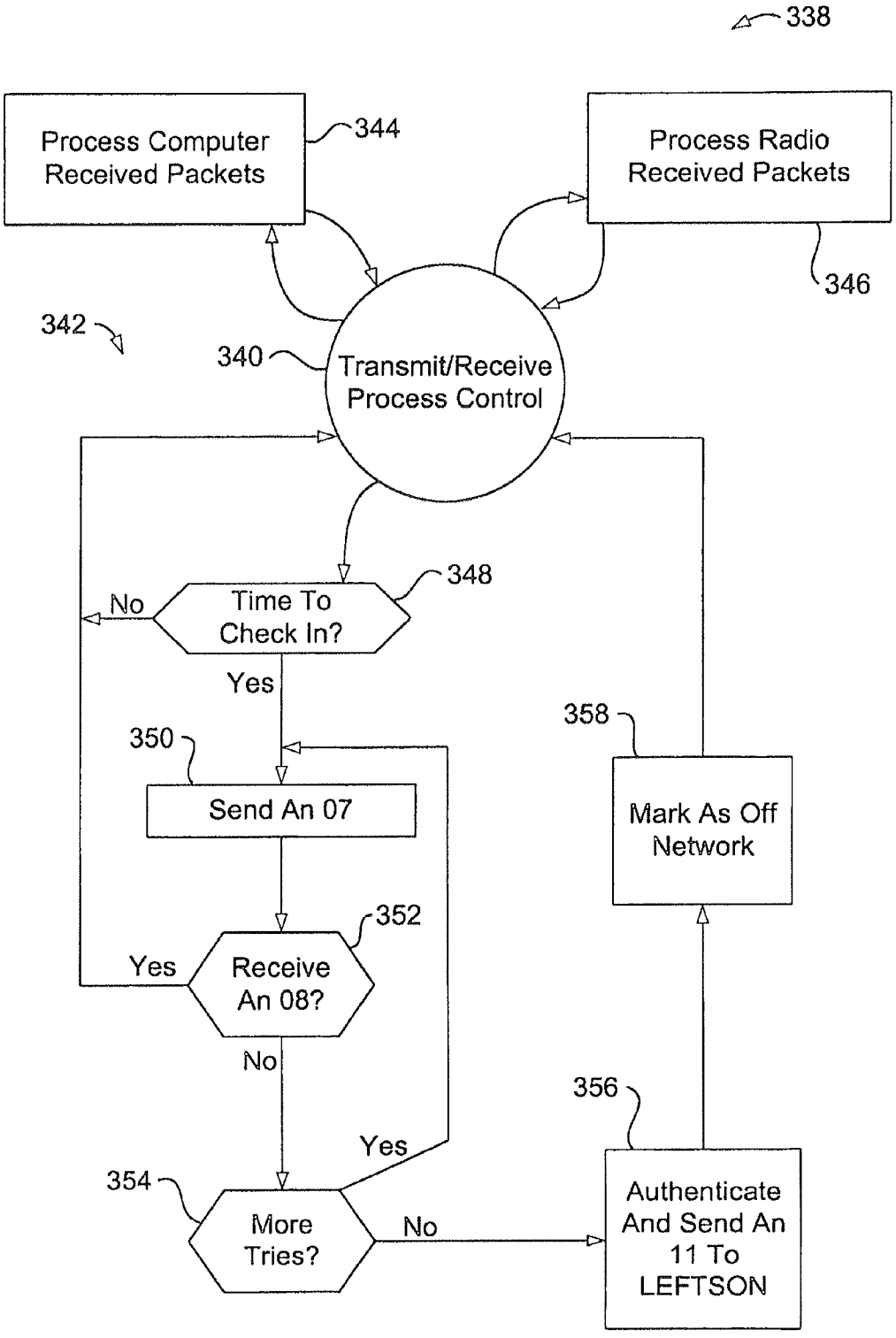

338
Process Computer Received Packets
344
Process Radio Received Packets
346
342
340
Transmit/Receive Process Control
348
No
Time To Check In?
Yes
350
Send An 07
352
Yes
Receive An 08?
No
358
Mark As Off Network
356
Yes
354
More Tries?
No
Authenticate And Send An 11 To LEFTSON

Fig. 16

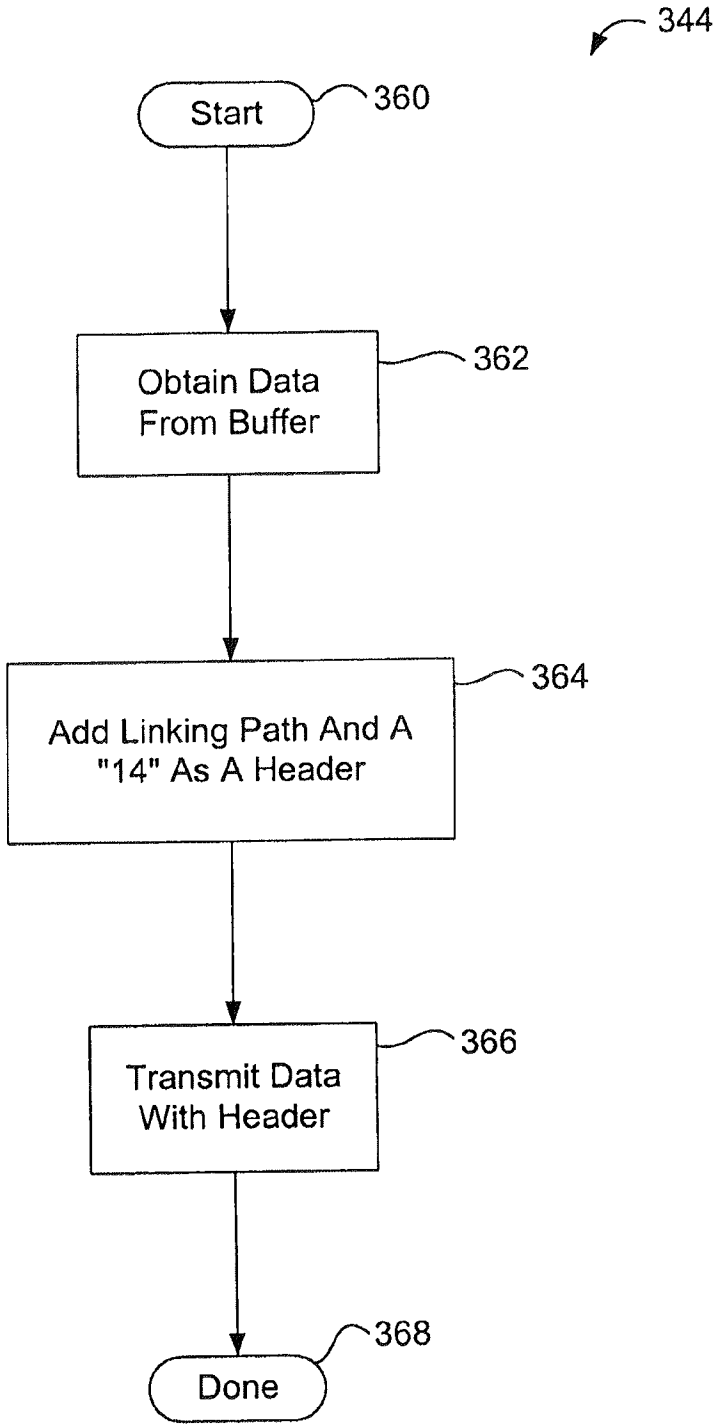

344
Start
360
Obtain Data From Buffer
362
Add Linking Path And A "14" As A Header
364
Transmit Data With Header
366
Done
368

Fig. 17

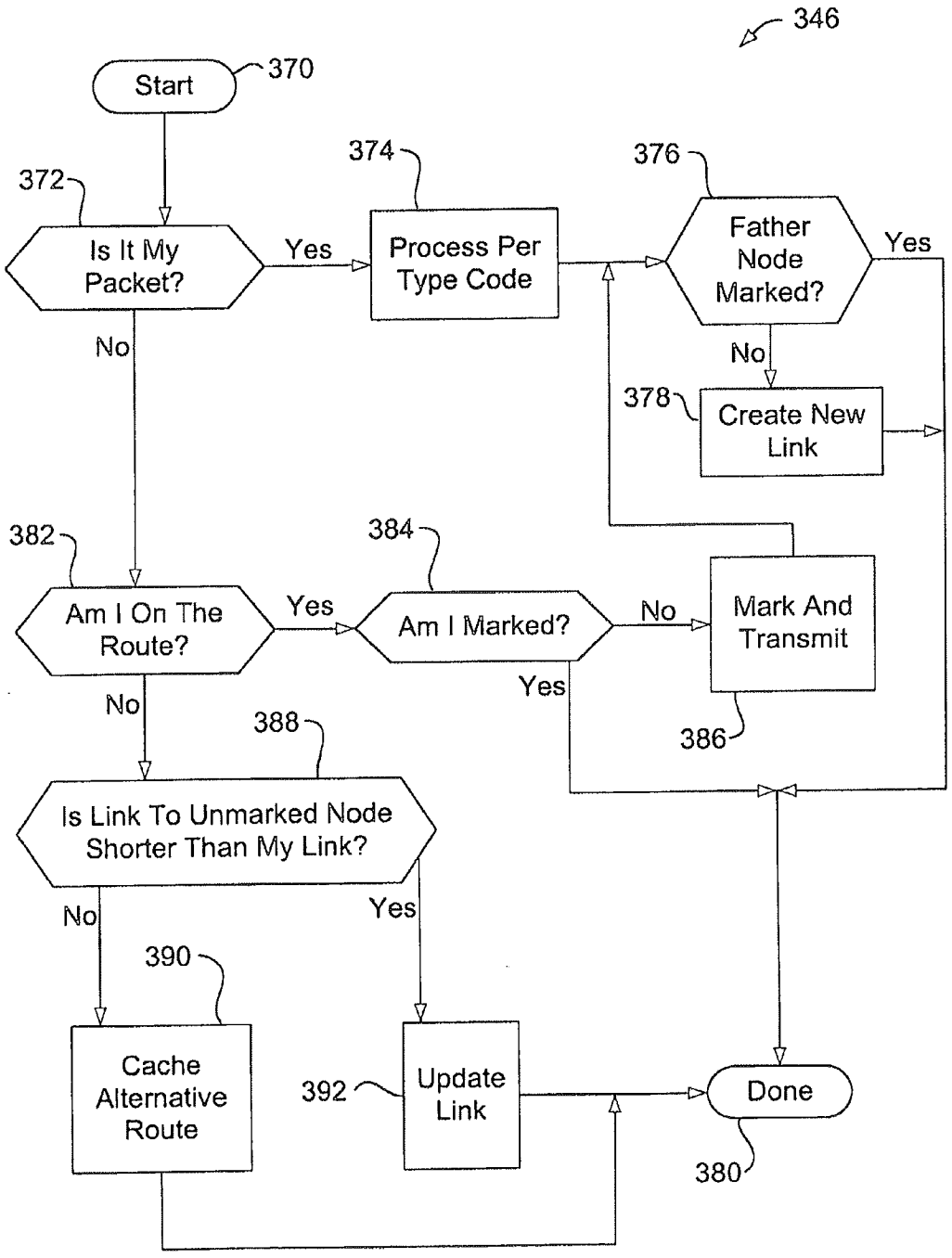

346
Start
370
372
Is It My Packet?
Yes
374
Process Per Type Code
376
Father Node Marked?
Yes
No
378
Create New Link
382
Am I On The Route?
Yes
384
Am I Marked?
No
Mark And Transmit
386
Yes
No
388
Is Link To Unmarked Node Shorter Than My Link?
No
Yes
390
Cache Alternative Route
392
Update Link
Done
380

Fig. 18

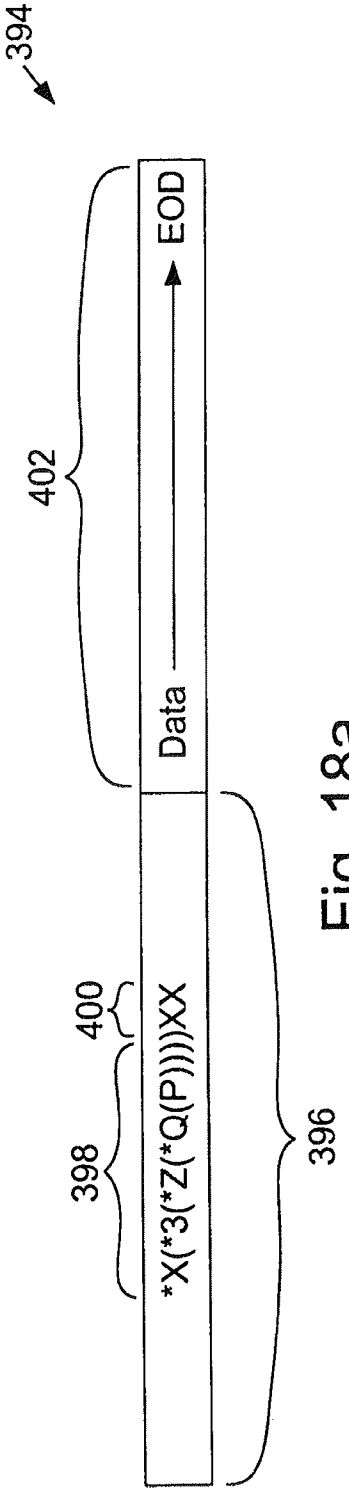


Fig. 18a

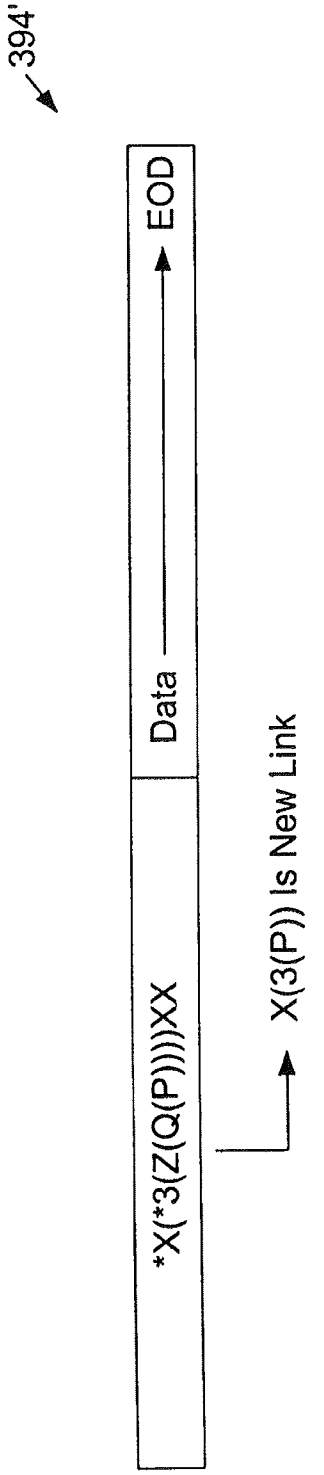


Fig. 18b

404 Code Received	406 Server Response	408 Client Response
01	02 + One-Way Seed	Drop
02	Drop	05 + One-Way Response
03	Drop	04 + Seed Or Null
04	Drop	05 + One-Way Seed
05	If 02 And Authentic Then 06 Else Drop	If 04 And Authentic Then 06 Else Drop
06	Drop	If 05 Then 07 Else Drop
07	08	Drop
08	Drop	Update Tree Or Repeat Data
09	Drop	10
10	Drop	Update Tree Or Repeat Data
11	Drop	Send 11 To LEFTSON With Address of Departer Plus 01 to Reconnect
12	Reserved	Reserved
13	Delete Sender	Drops
14	Send To Network Transmit Buffer	Send To Computer Transmit Buffer
86	Reserved	Reserved

Fig. 19

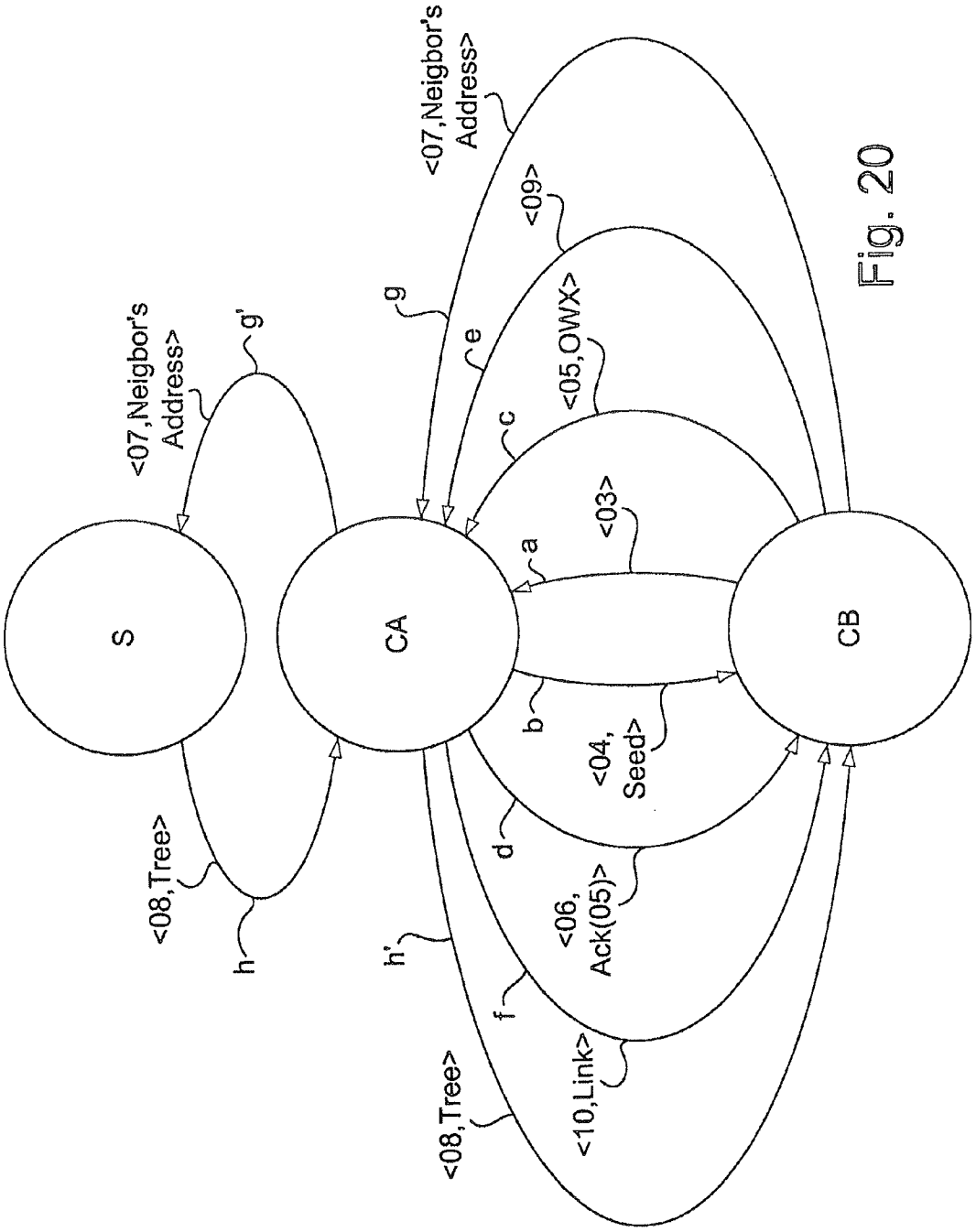

S
CA
CB
<07, Neigbor's Address>
g'
<07, Neigbor's Address>
g
<09>
e
<05, OWX>
c
<03>
a
b
<04, Seed>
d
<06, Ack(05)>
f
<10, Link>
<08, Tree>
h'
<08, Tree>
h

Fig. 20

X(3(9,Z(8,5,Q(P))),B)

Fig. 21a

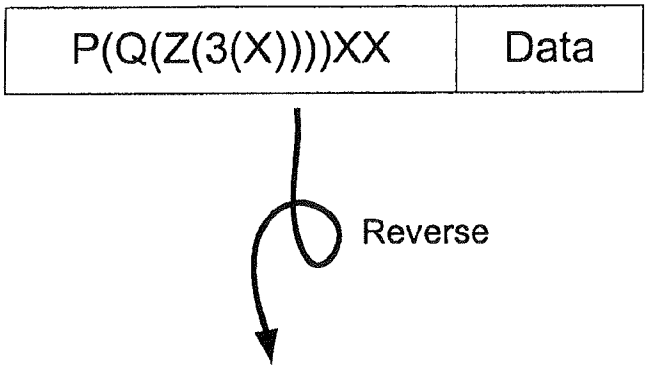


Fig. 21b

Fig. 21c

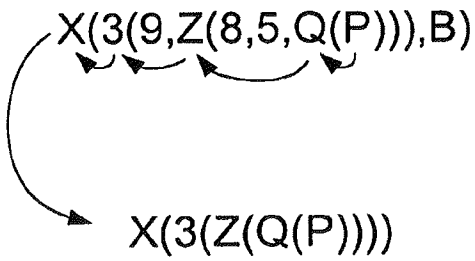


Fig. 21d

WIRELESS NETWORK SYSTEM AND METHOD FOR PROVIDING SAME

This application is a continuation of application Ser. No. 09/492,933, filed Jan. 27, 2000, now abandoned, which is a continuation of application Ser. No. 08/790,894, filed Dec. 6, 1996, now U.S. Pat. No. 6,044,062.

TECHNICAL FIELD

This invention relates generally to digital computer networks, and more particularly to wireless digital networks for the transmission of digital data packets.

BACKGROUND ART

There are many kinds of networks that can be used to couple computers together for data communication. For example, a simple local area network (LAN), such as a Novell® network or an Appleshare® network, can be used to couple together the personal computers in an office. Often, one or more network "servers" or "hosts" will influence data flow within the network and access to certain network functions such as a central file repository, printer functions, Internet gateways, etc. Other local area networks operate on a peer-to-peer basis without the use of servers.

A wide area network (WAN) is sometimes referred to as a "network of networks." The Internet is a WAN that has, of late, become extremely popular. The origins of the Internet date back several decades to a government-sponsored military/business/research WAN that was designed to remain operational even in the event of a catastrophic loss of a large portion of the network. To accomplish this goal, robust protocols and systems were developed which allowed a geographically distributed collection of computer systems to be connected by means of a network that would remain operational even if large portions of the network were destroyed.

While the use of the Internet has been prevalent for many years now, its use has been limited by the arcane and often difficult commands required to access the various resources of the network. To address this problem, a protocol known as the "World Wide Web" or "WWW" was developed to provide an easier and more user-friendly interface to the Internet. With the World Wide Web, an entity having a domain name creates a "web page" or simply "page" which can provide information and, to an ever greater extent, some interactivity with the web page.

The Internet is based upon a transmission protocol known as "Transmission Control Protocol/internet Protocol" (or "TCP/IP" for short), which sends packets of data between a host machine, e.g. a server computer on the Internet, and a client machine, e.g. a user's personal computer connected to the Internet. The WWW is an Internet interface protocol which is supported by the same TCP/IP transmission protocol. Intranets are private networks based on Internet standards, and have become quite common for managing information and communication within an organization. Intranets, since they subscribe to Internet standards, can use the same web browser and web server software as used on the Internet. Intranets are, in many cases, supplementing or replacing traditional local area network protocols.

Most, if not all, of the data communication links between the various machines of most networks are hard-wired. That is, client machines are typically coupled to a server and to other client machines by wires (such as twisted-pair wires), coaxial cables, fiber optic cables, and the like. In some

instances, some of the communication links can be wireless communication links, such as microwave links, radio frequency (r.f.) links, infrared links, etc., but this tends to be rare with most LANs.

The majority of so-called wireless networks use radio modems for data communication, although there are some IR networks available that work over very short distances, such as within a single large room. However, networks spanning larger areas will predominately use radio modems. GRE America, Inc. of Belmont, Calif. sells a number of spread-spectrum modems that can be used for the transmission of digitally encoded information. A number of wireless network services, such as Ricochet® network services (Ricochet is a subsidiary of Metrocom, Inc. of Los Gatos, Calif.) combine a radio modem with a portable personal computer to allow the personal computer to connect to the Internet. The Ricochet system operates by providing a large number of r.f. data transceivers within a given geographic area, that are often attached to telephone poles, and that are coupled to centralized server that serves as a gateway to the Internet.

The assumption made by the Ricochet system designers is that a given radio modem coupled to portable computer will be in radio contact with one, and only one, transceiver of the network. A data "packet" sent by the portable computer via the radio modem will be received by the transceiver and broadcast through the Ricochet network until it reaches a Wide Area Processor or WAP, where it is transmitted by twisted pair over the Internet to a Ricochet server connected to the Internet. Packets destined for a particular personal computer are received by the server of the Ricochet system, and are transmitted from each of the transceivers with the expectation that the radio modem of the destination portable computer will receive the data packets from one of those transceivers.

It should be noted that wireless communication systems such as the Ricochet system exhibit a number of drawbacks. For one, if the radio modem of the personal computer is not within transmission range of one of the transceivers of the Ricochet network, a connection cannot be made to the network. Furthermore, the Ricochet network can create a great deal of "packet duplication" or "pollution" as copies of a particular data packet are multiply repeated, rather than routed. This packet duplication can also occur if a radio modem of a particular personal computer is in radio transmission range of two or more transceivers of the Ricochet network. In such an instance, the two or more transceivers can each receive the data packets, and each proliferates copies of the data packet across the Ricochet network. While duplicate packets are ultimately discarded, such duplicate packets increase data congestion in the network and increases the work that must be performed by the server. In addition, since data packets are transmitted from all the transceivers of the Ricochet network, there may be packet duplication at the personal computer if it is in contact with more than one transceiver of the Ricochet network, and the bandwidth available from each transceiver is reduced since each transceiver is transceiving each client-destined data packet on the network. Also, since the data is transmitted to the Internet over twisted pair, there is a 28.8K baud bottleneck in the system, resulting is average system performance of even less than 28.8K baud. It is therefore apparent that prior art wireless networks of the Ricochet network type lack robustness (i.e. the ability to maintain communication with the network under adverse conditions) and exhibit a number of inefficiencies such as data packet proliferation.

Cellular telephone systems operate using a number of transceivers, where each transceiver occupies a "cell." As a mobile telephone moves from one cell to another, an elaborate and expensive land-based system causes the mobile telephone to be "handed-off" from the cell that it was previously in to the cell that it is entering. As noted, the equipment and system used for the hand-off is expensive and, further, such hand-off sometimes fail, dropping the telephone connection. Furthermore, individual radios at a given cell can handle only one call at a time, which is inadequate for many computer network systems.

Amateur radio ("Ham") operators have developed a peer-to-peer digital repeater system referred to as the AX.25 protocol. With this protocol, each peer repeats all data packets that it receives, resulting in rapid packet proliferation. In fact, with this protocol, so many packet collisions occur among the peers that the packets may never reach the intended peer.

Lastly, there is abundant reporting in the literature, but it cannot be substantiated, that the U.S. Military has a wireless communication system which allows digital information to be transmitted in a more robust and efficient matter. More specifically, it is suspected that the U.S. Military has a system in which digital data can follow multiple paths to a server that may include one or more clients of the network. However, source code listings, or source code in machine-readable form for these U.S. military systems remains secret and unavailable to the public. Some of the literature pertaining to this U.S. military technology is summarized below.

"Packet Radios Provide Link for Distributed Survivable Command Control Communications in Post-Attack Scenarios", M. Frankel, *Microwave Systems News* 13:6 (June 1983), pp. 80–108, discusses the SURAN (Survivable Radio Network) project and its relation to overall command and control communications (C^3) development

"Congestion Control Using Pacing in a Packet Radio Network", N. Goweer and J. Jubin, *Proceedings of Milcom* 82, (New York: IEEE Press, 1982), pp. 23.1–23.6, describes a technique for pacing flow control used in the DARPA packet radio project.

"Current Packet Radio Network Protocols", J. Jubin, *Proceedings of Infocom* 85 (New York: IEEE Press, 1985), pp. 86–92, is a systematic review of the various protocols currently used in the DARPA packet radio network. The article includes a discussion of pacing, route calculation, maintenance of route and connectivity tables, acknowledgment schemes, and other mechanisms. The article also provides a discussion on how the various protocols interrelate and reinforce each other.

"The Organization of Computer Resources into a Packet Radio Network", R. Kahn, *IEEE Transactions on Communications* COM-25:1 (January 1977), pp. 169–178, is a prospectus for the second generation of the DARPA radio project. This lead to the development of the DARPA Bay Area Packet Radio experimental work in the mid to late 1970's.

"Advances in Packet Radio Technology", R. Kahn, S. Gronemeyer, J. Burchfiel, R. Kunzelman, *Proceedings of the IEEE* 66z:11 (November 1978), pp. 1468–1496 is a survey of packet radio technology in the second generation of the DARPA packet radio project.

"Survivable Protocols for Large Scale Packet Radio Networks", G. Lauer, J. Westcott, J. Jubin, J. Tornow, *IEEE Global Telecommunications Conference.* 1984, held in Atlanta, Ga., November 1984 (New York: IEEE Press, 1984)

p. 468–471, describes the SURAN network, with an emphasis on network organizations and management protocols.

"Multiple Control Stations in Packet Radio Networks", W. MacGregor, J. Westcott, M. Beeler, *Proceedings of Milcom* 82 (New York: IEEE Press, 1982) pp. 10.3–10.3–5, is a transitional paper that describes design considerations involved in converting the DARPA packet radio network from single to multistation operation while eliminating the additional step to a fully hierarchical design. It focuses on the self-organizing techniques that are necessary in the multistation environment.

"Future Directions in Packet Radio Technology", N. Shacham, J. Turnow, *Proceedings of IEEE Infocom* 85 (New York: IEEE Press, 1985), pp. 93–9[8], discusses new research areas in packet radio, with some references to SURAN developments.

"Issues in Distributed Routing for Mobile Packet Radio Networks", J. Westcott, *IEEE Global Telecommunications Conference,* 1982 (New York: IEEE Press, 1982), pp 233–238, studies the issues involved in the DARPA packet radio network, prior to the availability of signal strength sensing from the radio receivers as a hardware capability on which to build. The paper describes issues that must be considered in evaluating the usability of an RF link and gives details of the alternate route mechanism used in the DARPA system to smooth temporary RF propagation problems that appear in a mobile node environment.

"A Distributed Routing Design for a Broadcast Environment", J. Westcott, J. Jubin, *Proceedings of Milcom* 82 (New York: IEEE Press, 1982), pp. 10.4-1–10.4-5, is a detailed study of the problems involved in connectivity and routing table management in stationless packet radio, including a discussion of algorithms proposed for the DARPA packet radio network.

There is, therefore, a great deal of literature describing packet radio systems. The prior art does not disclose, however, a packet-based wireless computer network that is both robust and efficient, wherein each client of the network can be efficiently and effectively in communication with a multiplicity of other clients and servers of the network, greatly multiplying the number of link choices available and, if conditions change, or if a better link to a server becomes known to a client, where the link for a client can be updated and improved.

DISCLOSURE OF THE INVENTION

The present invention includes a wireless network system which is particularly well adapted for connection to a wide area network such as an Intranet or the Internet. The wireless network system includes one or more servers which are coupled to the wide area network, and two or more clients capable of communicating with the server or with each other via radio modems. The communication in the wireless network system preferably takes the form of digital data packets, which are not too dissimilar from the TCP/IP data packets used over the Internet. However, the data packets of the present invention also include data routing information concerning the path or "link" from the source of the packet to the destination of the packet within the wireless network. The data packets also include a code indicating the type of packet being sent.

In operation, a client of the wireless network system of the present invention has either a direct or an indirect path to a server of the wireless network system. When in direct communication with the server, the client is said to be "1 hop" from the server. If the client cannot reliably commu-

nicate directly with the server, the client will communicate with a "neighbor" client which has its own path ("link") to the server. Therefore, a client can communicate with the server along a link that includes one or more other clients. If a client communicates with the server through one other client, it is said to be "2 hops" from the server, if the client communicates to the server through a series of two other clients, it is said to be "3 hops" from the server, etc. The process of the present invention preferably includes an optimization process which minimizes the number of hops from the clients to the servers, on the theory that the fewer the number of hops, the better the performance of the network. Alternatively, the optimization process can also factor in traffic and transmission reliability of the various links to determine the optimal path to the server.

A wireless network system in accordance with the present invention includes at least one server having a server controller and a server radio modem, and a plurality of clients, each including a client controller and a client radio modem. The server controller implements a server process that includes the controlling the server radio modem for the receipt and transmission of data packets from clients of the network. The client controller implements a client process including the transmission and receipt of data packets from the server and from other clients. Preferably, the client process of each of the clients initiates, selects, and maintains a radio transmission path ("link") to the server. As noted previously, this radio transmission path to the server is either a direct path to the server (1 hop) or an indirect path to the server (multi-hop) through one or more other clients. Preferably, the client process of a particular client also constantly searches for improved paths to the server.

A method for providing wireless network communication in accordance with the present invention includes providing a server implementing a server process, and providing a plurality of clients, each client implementing a client process. The server process includes receiving data packets via a server radio modem, sending data packets via the server radio modem, performing a "gateway" function to another network, and performing housekeeping functions. The client process includes the sending and receiving of data packets via a client radio modem, maintaining a send/receive data buffer in digital memory, and selecting links to the server. Again, the client process preferably chooses a "best" link to the server that is either a direct path or an indirect path through one or more other clients.

The server of the present invention provides a gateway between two networks, where at least one of the networks is a wireless network. The gateway function of the server makes any necessary translations in digital packets being sent from one network to the other network. The server includes a radio modem capable of communicating with a first, wireless network of the present invention, a network interface capable of communicating with the second network (which may or may not be wireless and, in fact, is preferably a wired TCP/IP protocol network), and a digital controller coupled to the radio modem and to the network interface. The digital controller passes data packets received from the first network that are destined for the second network to the second network, and passes data packets received from the second network that are destined for the first network to the first network, after performing any necessary translations to the data packets. The digital controller further maintains a map of the links of the first network and provides that map to first network clients on request. By maintaining a map of the first network links, the server is able to properly address packets received from either the first network or the second network to the appropriate client of the first network, and allows the client of the network to maintain and upgrade their data communication paths to the server.

A network client for a wireless communication network of the present invention includes a radio modem capable of communicating with at least one server and at least one additional client, and a digital controller coupled to the radio modem to control the sending and receiving of data packets. The digital controller is further operative to determine an optimal path to at least one server of the wireless network. The optimal path can be either a direct path to the server, or an indirect path to the server through at least one additional client.

The method, apparatus, and systems of the present invention therefore provide a wireless network that is both robust and efficient. Since each client of the network can potentially be in communication with a multiplicity of other clients and servers of the network, there are a great number of link choices available. If conditions change, or if a better link becomes known to a client, the link can be updated and improved.

These and other advantages of the present invention will become apparent upon reading the following detailed descriptions and studying the various figures of the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a pictorial representation of a wireless network system in accordance with the present invention;

FIG. **1***a* illustrates a first tree structure of the data communication paths or "links" of the wireless network system of FIG. **1**;

FIG. **1***b* illustrates a second tree structure illustrating optimized or "stabilized" data communication paths for the wireless network system of FIG. **1**;

FIGS. **2***a*–**2***g*, **2***h*'–**2***h*", and **2***i*–**2***o* are used to describe a prototype of the wireless network system of FIG. **1**, illustrating both the path connection and path optimization processes of the present invention;

FIG. **3** is a block diagram of a server, router, the first wireless network, and the second network of FIG. **1**;

FIG. **4** is a flow diagram of a server process of the present invention operating on the server of FIG. **3**;

FIG. **5** is a flow diagram of the "Process Packets Received From Client" step of FIG. **4**;

FIG. **5***a* illustrates a data packet processed by the process illustrated in FIG. **5**;

FIG. **5***b* is a flow diagram illustrating the process "Am I on Route?" of FIG. **5**;

FIG. **5***c* is a flow diagram illustrating the process "Data?" of FIG. **5**;

FIG. **6** is a flow diagram illustrating the "Process Internodal Information" process or FIG. **5**;

FIG. **6***a* is a flow diagram illustrating the process "Client Authentic?" of FIG. **6**;

FIG. **6***b* is a flow diagram illustrating the process "Put New Client In Tree" of FIG. **6**;

FIG. **7** is a flow diagram illustrating the function "ADDSON(P,C)" of FIG. **6***b*;

FIGS. **7***a* and **7***b* are used to illustrate the operation of the ADDSON function of FIG. **7**;

FIG. **8** is a flow diagram illustrating the "Delete Client From Tree" process of FIG. **6**;

FIGS. **8***a*–**8***c* illustrate the process of FIG. **8**;

FIGS. **9***a*–**9***c* illustrate the "Place Network Tree In Client Transmit Buffer" of FIG. **6**;

FIG. **10** is a pictorial representation of the "Communicate With Network" process of FIG. **4**;

FIG. **11** is a flow diagram of the process "Communicate With Network" of FIG. **4**;

FIG. **12** is a block diagram of a radio packet modem used in the present invention;

FIG. **13** illustrates a client, such as a client A, B, C, or D of FIG. **1**;

FIG. **14** is a flow diagram of a client process running on the client of FIG. **13**;

FIG. **15** is a flow diagram of the process "Radio Transmit and Receive Packet" of FIG. **14**;

FIG. **16** is a flow diagram of the process "Perform Transmit/Receive Process" of FIG. **15**;

FIG. **17** is a flow diagram of the process "Process Computer Receive Packets" of FIG. **16**;

FIG. **18** is a flow diagram of the process "Process Radio Received Packets" of FIG. **16**;

FIGS. **18**A and **18**B are used to illustrate the process "Is It My Packet?" of FIG. **18**;

FIG. **19** is used to illustrate the "Process Per Type Code" of FIG. **18**;

FIG. **20** illustrates an initialization routine of the client process of the present invention; and

FIGS. **21***a*–**21***d* illustrate the process of FIG. **20**.

BEST MODES FOR CARRYING OUT THE INVENTION

FIG. **1** illustrates a wireless network system **10** in accordance with the present invention. The wireless network system **10**, which will also be referred to herein as a "first network," is preferably in communication with a second network **12** via a digital communication bridge or router **14**. The construction and operation of networks, such as second network **12**, and bridges or routers, such as router **14**, are well-known to those skilled in the art. It the present invention, it is preferred that the second network operates on the aforementioned TCP/IP protocols, i.e. the second network is the Internet or is a private Intranet. At times, herein, the second network will be referred to as simply the Internet, it being understood that other forms of a second network are also operable with the systems, apparatus, and processes of the present invention. Again, the construction and operation of the Internet and Intranets are well-known to those skilled in the art. Likewise, routers, bridges, and other network devices such as hubs, gateways and Ethernet interfaces are well-known to those skilled in the art, and are available from a variety of sources including Cisco Systems, 3-Com, Farillon, Asante, etc. In general, as a "network interface" will refer to any such device that allows a server of the wireless network system of the present invention to communicate, directly or indirectly, with the second network.

The wireless network system **10** of the present invention includes one or more servers **16**, the single example of which is herein labeled S. It should be noted that the server **016** serves as a gateway in that it performs a translation service between the first network and the second network. For example, the data packets on the first network include links and data types that are only applicable to the first network. Therefore, such links and data types are removed from the data packets before they are transmitted to the second network which, as noted previously, preferably operates on a TCP/IP protocol. Conversely, data packets received from the second network are modified to include the links and data types before they are transmitted to the first network.

Therefore, the data packets on the first or wireless network can be essentially "packages" or "envelopes" for TCP/IP data packets when they are destined for the Internet or received from the Internet. However, as will be discussed in greater detail subsequently, the data packets of the first network can be of types other than "data" types for TCP/IP formatted data. It should also be noted that while only a single server S is shown in this example that, in most cases, multiple servers, each with their own gateway to the Internet, will be used in the first network.

The wireless network system **10** further includes a number of clients **018**, each including a client machine **20** and a radio modem **22**. The client machine **20** can be any form of digital processor, including a personal computer (PC), a computer workstation, a personal digital assistant (PDA), etc. In the present invention, the client machine **20** is preferably a personal computer (PC) made to the Microsoft Windows/Intel microprocessor ("Wintel") standard, or to the Apple Macintosh standard. Wintel and Macintosh compatible computers are commercially available from a variety of vendors. Likewise, computer workstations and PDAs are available from a number of vendors. Radio modems, such as the radio modem **22**, are further available from a number of vendors. The present invention has been implemented using radio modems produced by GRE America, Inc. which operate on a spread spectrum technology, and which provide good receiver sensitivity and repeater capabilities. These GRE America, Inc. radio modems are commercially available under the Gina trademark and operate in the 2.4 gigahertz or 90 megahertz bands with support for packetized transmission. The Gina radio band modems further include error detection and correction, can operate in asynchronous or synchronous modes, and can support data speed from 300 to 64 kbps. Furthermore, the Gina radio modems can operate in a point-to-point or a point-to-multipoint mode.

A server process, to be discussed in greater detail subsequently, is implemented on the server **016** and a client process, also to be discussed in detail subsequently, operates on each of the clients **018**. In the present invention, the client process operates, at least in part, on the client machine **20**. However, in alternative embodiment of the present invention, the client process can operate on the controller of the radio modem **22** of the client **018**.

In wireless network system **10** illustrated in FIG. **1**, the client **018**A is in "direct" radio communication with the server **016** as indicated by the radio communication link **26**. This will be referred to herein as "direct" or "1 hop" or "line-of-sight" connection with the server **016**. The client **018**B, however, does not have a direct path or "link" to the server **016** due to an obstacle **24**, such as a hill, a large building, etc. Therefore, the client **018**B communicates via a radio link **28** with client **022**A which relays the data packets from client **018**B to the server **016**. A client **018**C has a direct line-of-sight to the server **016**, but is out of transmission range to the server **016**. Therefore, the client **018**C transmits its data packet by a radio link **30** to client **018**B, from where it is relayed to client **018**A via link **28**, for eventual relay to the server S via radio link **26**.

As noted in FIG. **1**, **018**D is in direct communication with server **016** via radio communication link **32**. If client **018**C detects the transmissions of client **018**D, it will note that client **018**D has less "hops" to the server **016** than does client **018**B, and will switch its link from client **018**B to client

018D. This process is a part of the "stabilization" or "optimization" process of the network **10**.

It will therefore be appreciated that the wireless network **10** of the present invention is constantly attempting to optimize itself for the "best" data transmission. In the embodiment described herein, this optimization looks solely to the number of hops between the client and the server for the sake of simplicity. However, other factors can also affect the quality of the data transmission. For example, the traffic of data packets through a particular client modem may be large, such that it is better to route the data from neighboring clients through other clients, even though there may be more hops involved with this alternative routing. Also, some radio links may be less robust or may be slower than other links, such that optimization may result in a routing of data around the less robust or slower links, even though it may increase the number of hops to the server **016**. Therefore, although the present preferred embodiment looks at only one single factor in its optimization processes, it will be appreciated by those skilled in the art that multiple factors can be used to stabilize or optimize the wireless network system **10** of the present invention.

It should also be noted that the wireless network system **10** of the present invention is quite robust in that it will survive the loss of one or more clients of the system. For example, if the client **018**A is lost due, for example, to a power or system failure, the data packets for client **018**C can be routed through the client **018**D, and the data packets for the client **018**B can be routed through clients **018**C. Therefore, the wireless network system **10** is highly robust and highly survivable under a number of adverse conditions.

In addition, the present invention permits mobile communication within the wireless network system **10**. For example, if the client **018**D is a portable computer and is moved around within the wireless network system **10**, it will opportunistically change its data communication path as better links become available. For example, if the client **018**D is moved close to the client **018**B, it may use the client **018**B as its link to the server **016**. Also, any routing through the client **018**D from other clients (such as **18**C in this example) will be updated and optimized as the data path for the client **018**D changes.

It should be noted that, in general, the network will work the best and will be the most stable if the radio modems and their client/controllers are never turned off. It is therefore desirable to not have an on/off switch on the radio modem, so that clients are always participating in the network traffic distribution. However, even if a radio modem is turned off, the remaining clients will re-route through other clients, as will be discussed subsequently.

In FIGS. **1***a* and **1***b*, two "tree" structures are shown illustrating the various links that were discussed, by way of example, with reference to FIG. **1**. The tree structure is maintained in the server S, and is transmitted to any client that may request it.

In FIG. **1***a*, a tree indicates that client **018**A is linked to server **016** by a link **26**, client **018**B is linked by link **28** to client **018**A and by link **26** to the server, and client **018**C is linked by line **30** to client **018**B, by link **28** to client **018**A, and by line **26** to the server **016**. The client **018**D is in direct communication with the server **016** via radio link **32**. Therefore, clients **018**A and **018**B are both "1 hop" away from the server **016**, client **018**B is "2 hops" away from server **016**, and client **018**C is "3 hops" away from server **016**.

In the scenario where client **018**C realizes it has a better connection to server **016** through the client **018**D, the link **30** to client **018**B is no longer used, and a new radio link **34** to client **018**D is established. This is illustrated in FIG. **1***b*. Now, clients **018**A and **018**B remain 1 hop clients, clients **018**B remains a 2 hop client, but client **018**C is upgraded from a 3 hop client to a 2 hop client. Therefore, the data transmission efficiency of the network has been "stabilized" or "optimized."

It should be noted that the term "link" is used to convey both the connection to an adjacent client as well as the entire path from a client to a server. It will therefore be understood that when speaking of a link to an adjacent client, that this also implicitly includes all necessary links from that adjacent client to the server, i.e. a link is the entire path description from a given client to a given server.

FIGS. **2***a*–**2***o*, an exemplary wireless point-to-multipoint network in accordance with the present invention is prototyped to facilitate a discussion of the theory and operation of the present invention. In FIG. **2***a*, a network **36** with 60 potential "nodes" **001** through **060** is illustrated. As used herein, a "node" can either be a client or a server. The nodes **014** and **016** have been arbitrarily selected as servers for the purpose of this example. The nodes **014** and **016** are marking servers with the large, black dot replacing the leading "0" of those numerals. For the purpose of this example, it is assumed that a node can only communicate with an immediately adjacent node. Of course, in actual operation, nodes may be able to communicate with more distant nodes than its immediate neighbor nodes.

It should be noted, that in the notes incorporated of FIGS. **2***b* through **2***k* the leading "0"s have been delcted from client umbers e.g. client **005** is referred as client **5** in FIG. **2***b*. This notation is used for clients with respect to clients and servers and the notation should not be confused with any other uses of the reference numerals **1** through **60** in this document.

FIG. **2***b*, a first client is designated at node **005** (hereafter "client **005**"). For the purposes of this example, the Yen or ¥ symbol is positioned next to the client **005**. As noted previously, for the purpose of this example, we will assume that any particular node is only in radio communication range of a node that is adjacent in a horizontal, vertical, or diagonal direction, i.e. in an immediately adjacent "neighbor." In this instance, client **005** detects that there is a radio contact with node **014**, which is a server (hereafter "server **014**"). The server **014** and the client **005** will build a routing path or "link" between each other. This is accomplished by client **0005** transmitting a "I Am Alive" packet seeking a route to a server. The server **014**, being within radio transmission range, will respond and will add the client **005** to its routing table as its "left son." The meanings of the "routing table" and the "left son" will be described subsequently. The routing table of the server **014** is therefore **014**(**005**), and the route from the client **005** to the server **014** is **005**>**014**. Again, this notation will be discussed in greater detail subsequently.

The network **36** then has a second client **6** added as indicated by the ¥ symbol next to node **006** in FIG. **2***c*. Second client **006** makes radio contact with client **005** and builds a routing path or a "link" to a server **014** through the client 05. Server **014** updates its routing table accordingly. This is accomplished by client **006** issuing an "I Am Alive" packet seeking a client repeater route to a server. Client **005** will respond and add client **006** to its routing table as its left son. The updated routing table of the server **014** is therefore: **014** (**005**)**006**)). The route from the user client node **006** to the server **014** is **006**>**005**>**014**.

In FIG. **2***d*, a third client **007** is added to the network **36** as indicated by the "¥" symbol next to node **007**. Client **007**

establishes contact with client **006** and finds a path through clients **006** and **005** to server **014**. This is accomplished by client **007** issuing a "I Am Alive" packet seeking a client repeater route to the server **014**. Client **006** will respond and add client **007** to its routing table as its left son. The updated routing table of the server **014** is then: **014(005(006(007)))**. The route from client 007 to the server **014** is: **007>006>005>014**.

In FIG. **2***e*, another client **016** has been added at node **016** as indicated by the "Y" symbol. It should be noted that client **016** can make radio contact with clients **005**, **006**, and **007**. However, client **016** recognizes node **026** as being a server (hereafter "server **026**") and then connects directly to server **026**. This is accomplished by client **016** transmitting a "I Am Alive" packet seeking a route to a server. The server **026** will respond and will add client **016** to its routing table as its left son. The updated routing table of server **026** is then **026** (**016**). The routing from client **016** to the server **026** is **016>026**.

In FIG. **2***f*, a server routing table and a route for each client thus far in the example are illustrated. It should be noted that when client **016** came into existence, a shorter route was created for client **007** to a server, namely via client **016** to server **026**. As noted in this figure, client 007 has made the adjustment to connect to server **026**, thereby "stabilizing" or "optimizing" the network **26**. Also, it should be noted that server **014** has deleted client **007** from its routing table, since client **007** is now using server **026** as its gateway to the Internet. This creates a universe of six nodes, of which two are servers and of which four are clients. The average "hop" distance from a client to a server is 1.5 hops. The remainder FIGS. **2***g*–**2***o* further illustrate these concepts.

In FIG. **2***g*, the network **36** illustrates an extreme example where 58 clients are connected to the two servers **014** and **026**. FIGS. **2***h*' and **2***h*" show a fully "stabilized" or "optimized" network where the path or "link" from any client to a server is as short as possible, i.e. where there is few "hops" as possible. It should be noted that the optimization occurs dynamically during operation and without complex algorithms and look-up tables. As will be discussed in greater detail subsequently, the optimization occurs when clients "hear" transmission from other clients that have a better (i.e. shorter) path to a server.

FIG. **2***h*' shows the network as seen from the point of view of servers **014** and **026** and from the point of views of clients **001**–client **031**. In FIG. **2***h*", the network as seen from the point of view of clients **032**–**060**, along with statistics for the overall network, are shown. In brief, in a universe of 60 nodes, of which two are servers and 58 are clients, the average hop distance from a client to a server is 2.36206897 hops.

In FIG. **2***i*, the process of adding a new client **009** to the server is illustrated. The first time that client **009** came "alive" (i.e. became operational) it took five tries before node **009** found a client neighbor with the path to the server. The reason that it may take many tries to find a connection path is that multiple neighbors of client **009** are responding to client **009** "I Am Alive" message via CSMA/CD (Carrier Sent Multiple Access/Collision Detection) protocol. The likelihood that any particular neighbor of client **009** will respond first is, essentially, random. Once client **009** hear from a neighbor that it does not have a path to a server, client **009** tells that neighbor not to respond to the next "I Am Alive" announcement from client **009**. In consequence, client **009** keeps trying to find a path to the server until it succeeds. However, that path may not be the shortest path. In this example, the client **009** finds a path to the Internet server, resulting in the updating of the routing table for the Internet server **014** as **014** (**005**(**006**(**007**(**008**(**009**)))),**004**, **003**). The route or "link" from client **009** to the server is: **009>008>009>006>005>014**.

In FIG. **2***j*, a client **029** is finding a route to the server via one of its neighbors. It finds a route through client **019**, and is added to the routing table of client **019** as its left son. The routing table of server **014** is also updated, and the route from user client **029** to the server is determined. However, this route is not an optimal route in that it includes a greater number of hops than necessary.

In FIG. **2***k*, the "stabilization" or "optimization" process is illustrated. It was previously noted that the client **029** has a non-optimal path to its server. In order to improve this path, client **029** will receive "help" from its neighbors starting with client **007**. Client **007** currently has a route to server **014**. Client **007** starts randomly probing its neighbors looking for a shorter route to a server. Client **007** finds a shorter route to client **026**. Client **7** informs server **014** to drop client **007** from server **014**'s routing table, and client **007** informs server **026** to add client **007** to its routing table. Since client **029** was "downstream" from client **007**, client **029** dynamically becomes switched to a route to server **026**.

In FIG. **21**, this process is repeated for client **008**. Notably, client **008** shortens its route to server **026** by 1 hop. Client **009** cannot improve its route to server **026**.

In FIG. **2***m*, client **018** shortens its route to server **027** to 2 hops. This is despite the fact that the route through clients **007** and **008** are a relatively efficient 3 hop links.

In FIG. **2***n*, client **029** is optimizing its path. Client **029** eliminates **018** from its route by "leap frogging" past client **018** with the result of the shortest possible 3 hop route to a server. Ultimately, therefore, client **029** route has improved from a 7 hop path through server **014** to the shortest possible 3 hop path to server **026**. This result is dynamically accomplished with the efficiencies of client **007**, **008**, and **018** also improving, and without the need for complex routing algorithms.

In FIG. **2***o*, another example of individual dynamic routing is illustrated for client **044**. This client node shortens its route from 3 to 2 hops by switching server destinations. Client **044** drops out of the server **014**'s routing table and gets added to server **026**'s routing table.

The advantage of prototyping the system as explained in FIGS. **2***a*–**2***o* is that further optimizations become apparent. For example, if a great deal of network traffic is going to a particular node, it may be desirable to place a "passive repeater" at that node. A passive repeater is not a client, per se, but, rather, is a transceiver that receives and rebroadcasts packets. The passive repeater therefore effectively extends the range of the transmitting clients, and reduces data bottlenecks in the system. A passive repeater is also useful for clients with long links to a server in that it can shorten the link by effectively allowing to skip some intermediate links. The prototyping of the system is also useful in that it shows that placing servers near the center of the network reduces the average link length (i.e. reduces the average number of client hops) in the network.

In FIG. **3**, a block diagram of the server **16** of FIG. **1** is illustrated. In this instance, the server **16** includes a computer system **38** and a number of peripherals coupled to the computer system. The computer system **38** can be a personal computer system, a computer workstation, or a custom data processor capable of implementing the processes of the present invention.

By way of example, the computer system **38** includes a microprocessor **42** that is coupled to a memory bus **44** and

to an input/output (I/O) bus **46**. Typically also coupled to the memory bus **44** are random access memory (RAM) **48** and read only memory (ROM) **50**. The RAM **48** is usually volatile (i.e. its contents are lost when power is removed) and is used for temporarily or "scratch pad" memory. The ROM **50** is non-volatile (i.e. its contents are not lost when power is removed), and typically includes the start-up instructions for the computer system **38**. A number of peripherals are typically coupled to the I/O bus **46**. For example, a removable media drive **52** for a removable media **54** (such as a floppy disk, a Zip® disk, or a C/D ROM) is typically coupled to the I/O bus **46**, as is a fixed or hard disk **56**. Furthermore, a router **14** or bridge can be used to couple the I/O bus **46** to the Internet **12** as previously described. In addition, an RJ45 Ethernet interface **58** can be used to couple the computer system **38** to a local area network **60** and from there to the Internet **12** by a router **14**, or the like. Also, a radio modem **62** (including a control section C, a radio section R, and an antenna **64** coupled to the radio section R) can be coupled to the I/O bus **46**. The radio modem **62** can communicate with the network **10** including a number of nodes **66** by a wireless transmission of "radio link **68**." The assembly of the hardware of the server illustrate in FIG. **3** will be apparent to those skilled in the art.

In FIG. **4**, a server process **70** of the present invention is implemented on the server **16**. More particularly, the server process **70** can be implemented on computer system **38**, within the control section of the radio modem **62**, or partially in both of those places. In the present preferred embodiment, the majority of the server process **70** is implemented on the computer system **38**. However, it should be noted that the control section C of the radio modem **62** includes a microprocessor and memory and, with proper program instructions, can be made to implement the process **70** of FIG. **4**, freeing the personal computer **38** for other tasks.

The server process **70** includes a server process control **72** and four subprocesses. More particularly, the subprocesses include a process **74** which processes received from clients, a process **76** which sends packets, a process **78** which communicates with the network, and a process **80** which performs housekeeping functions. Each of these processes will be discussed in greater detail subsequently.

In FIG. **5**, the process "Process Packets Received From Clients" **74** of FIG. **4** is illustrated in greater detail. The process **74** begins at **82**, and in a step **84**, the variable RETRY is set to 0. Next, a step **86** retrieves a packet from the client receive buffer, and a decision step **88** determines whether the path or "link" of the packet is same as the currently stored link in memory. If not, a step **90** updates the tree. If so, or after the updating of the tree in step **90**, a decision step **92** determines whether it is "My Packet?" In other words, step **92** determines whether the packet being received by the server was intended for that server. If not, a decision step **94** determines whether that server is on the route. If that server is on the route, but it is not its packet, a decision step **96** determines whether the packet has already been repeated. If not, the packet is placed in the client transmit buffer. If decision step **94** determines that the server is not on the route, or the packet has already been repeated, or upon the completion of step **98**, a decision step **100** looks for time-out. The time-out is provided by the server process control **72** such that the computer hardware resources on which process **70** are implemented can be shared among the four processes. More particularly, in most instances, the computer hardware resources are shared among the subprocesses **74**–**78** in a "round-robin" fashion well-known to those skilled in the art. However, it should be noted that at times the strict round-robin scheduling is not adhered to, as will be discussed subsequently.

If step **100** determines that a time-out has occurred, the decision step **102** determines whether the retry number RETRY is greater than the number of retries allowed, namely NUMRETRY. In its preferred embodiment, the number of retries RETRY are set at, perhaps, 2 or 3 so that the server does not tie up its resources with endless metrics of the process. If RETRY is greater than NUMRETRY, the process is completed as indicated at **103**. Otherwise, a step **104** increments RETRY by 1. In the absence of a time-out and in the absence of the number of retries being used up, process control returns to step **86**.

If step **92** determines that the packet is for that server, a step **106** determines whether the packet is a data type. If not, a step **108** processes "internodal information." If so, a step **110** places the data in a server transmit buffer. After the completion of steps **108** or **110**, process control is returned to step **100** to determine if there is a time-out.

In FIG. **5***a*, a "data packet" **112** in accordance with the present invention is illustrated. As it will be appreciated by those skilled in the art, a data packet is an associated string of digital information that is transferred and processed as a unit. The data packet **112** of the present invention includes a header **114**, a type **116**, and data **118**. The data **118** can be standard TCP/IP data. The header **114** includes the source address, the address of all hops along the way (i.e. the "link" of the data packet), and the destination address. Hops (i.e. clients and servers) that already have been traversed (i.e. have already forwarded the data packet) are indicated with an asterisk ("*") symbol. The type **116** is, in this implementation, a two digit code indicating the type of the data packet **112**, as will be discussed in greater detail subsequently. The data section **118** of the data packet **112** includes the data associated with that packet. In the present invention, the data section is in the range of 128–1024 bytes in length.

In FIGS. **5***b* and **5***c*, respectively, the decision steps **94** and **106**, respectively are illustrated with respect to the data packet architecture of FIG. **5***a*. The decision step **94** ("Am I On Route?") of FIG. **5** is simply determined by the process **120** "My Address In the Header?" If yes, the process of FIG. **5** branches to step **96**, and if no, the process of FIG. **5** branches to step **100**. In FIG. **5***c*, the decision step **106** "Data?" simplifies to a process **122** "Is the Type Equal to 14?" This is because, in the present invention, a type **14** has been arbitrarily chosen to indicates a data type. If yes, the process of FIG. **5** branches to step **100**, and if no, the process of FIG. **5** branches to step **108**.

In FIG. **6**, the step **108** "Process Internodal Information" of FIG. **5** is explained in greater detail. The process **108** begins at **124** and, in a multi-branch decision step **126**, the type of the data packet is determined. If the type is a "01," a step **128** places an acknowledgment and a "code seed" in the client transmit buffer, and the process is completed at **130**. Acknowledgments and "code seeds" will be discussed subsequently. It the type is a "07," a step **132** receives the client request for the network tree, and the process places the network tree in the client transmit buffer in a step **134**. The process is then completed at **130**. If, however, the type is "13," a step **136** deletes the client from the tree and a step **138** determines whether a flag has been set. If not, the process is completed at **130**. If, the flag has been set as determined by step **138**, a step **140** puts a new client in the tree and the process is then completed at **130**.

If decision step **126** determines that the type is "05," a step **142** determines whether the client is authentic. The authentication process, which will be discussed subsequently,

keeps unauthorized clients from being added to the network. If the client is not authentic, the process is completed at **130** and the client is not allowed to connect to the server. If step **142** determines that the client is authentic, a step **144** determines whether the client is already in the server tree. If yes, the flag is set in a step **146** and process is control is turned over to step **136** to delete the client from the tree. Since the flag has been set, step **138** branches the process control to step **140** and the new client is placed in the tree, after which the process is completed at **130**.

The addition and removal of nodes from trees are well known to those skilled in the art. For example, in the book, incorporated herein by reference, *SNOBOL* 4: *Techniques and Applications*, by Ralph E. Griswald, Department of Computer Science, University of Arizona, Prentiss-Hall, Inc., © 1975, ISBN 0-13-853010-6, algorithms for placing and removing clients from trees are discussed.

FIG. **6***a* illustrates the process **142** of FIG. **6** in greater detail. More particularly, the process **142** begins at **148** and, in a step **150**, a "seed" is chosen on the fly. Next, in a step **152**, a "one-way" function is performed using the seed and a known authentication algorithm, and a one-way result is stored. Next, found in step **154**, the seed is "camouflaged," and in a step **156**, places an acknowledgment code and the camouflaged seed in the client transmit buffer. The process is then completed at **158**.

The purpose of the process **142** is to prevent unauthorized "clients" from accessing the network. For example, hackers can be prevented from accessing the network unless they can crack the authentication process, which is nearly impossible.

Authentication techniques are well known to those skilled in the art. For example, the book, incorporated herein by reference, *Algorithms in SNOBOL* 4, by James F. Gimpel, Bell Telephone Laboratories, John Wiley & Sons, a Wiley Interscience Publication, © 1976 by Bell Telephone Labs, Inc., ISBN 0-471-30213-9, describes authentication techniques using one-way seeds. See, in particular, pp 348–349 with back-references. In brief, a "seed" is chosen "on the fly", such as by reading the system clock. The one-way function modifies the seed using an algorithm known to both the server and the clients. The one-way result, which in this instance is 4 bytes in length, is stored. The step **154** then "camouflages" the seed by dispersing the 4 bytes among perhaps 26 other bytes prior to transmitting the camouflaged seed. The receiving clients know which of the four bytes to use for their one-way function.

The process **140** "Place New Client In Tree" of FIG. **6** is illustrated in greater detail in FIG. **6***d*. The process **140** begins at **160** and in a step **162**, it is determined whether this is a "1 hop" client. If so, a decision step **164** determines whether it is a new client C. If so, the variable P is set to S in step **166** and the function "ADDSON" with the variables (P, C) is evoked. S, of course, is the server or root of the tree. If step **64** determines that it is not a new client C, or after the completion of the ADDSON function, the process ends at **170**.

If step **162** determines that it is not a 1 hop client (i.e. C is a multi-hop client) a step **162** determines whether the parent P of client C is known to client C. If not, a step **174** determines the parent P from the header of client C. If the client C does know its parent, or after the completion of step **174**, a step **176** receives parent P from client C. Next, in a step **178**, the function ADDSON(P,C) is evoked, and the process is completed at **170**.

In FIG. **7**, the ADDSON(P,C) function is explained in greater detail. More particularly, function steps **168**–**178** begin at **180** and, in a step **182**, the variables C, P are received. In this notation, the string RSIB( ) refers to a string of right siblings, and the notation LSON( ) refers to a string of left sons. A step **184** sets RSIB(C)=LSON(P). A step **186** sets a string FATHER(C)=P and a step **188** sets the string LSON (P)=N2 is an in-memory pointer that points to the memory location of nodes. The string FATHER provides a pointer from a child C to its father, which in this case is P. The process is then completed as indicated at **190**.

In FIGS. **7***a* and **7***b*, the ADDSON function is graphically illustrated. In FIG. **7***a*, a parent **192** has left a son **194** and a right sibling **196**. The parent **192** and left son **194** have mutual pointers to each other, while the right sibling **196** has only a pointer to the parent **192**. The left son **194** also has a pointer to the right sibling **196**. When the ADDSON function is evoked with the argument (P, C) C is added as the left son **198** and the pointer in the parent **192** is updated to point to the left son **198**. The left son **198** has pointers to the parent and to the new right sibling **194**. The new right sibling **194** still has a point to the older right sibling **196**, and both siblings **194** and **196** have pointers to the parent **192**. It should be noted, under all circumstances, that the parent is only directly aware of the left son, in that it only has a pointer to the left son.

In FIG. **8**, the process **136** "Delete Client From Tree" is illustrated in flow-diagram form. The process **136** begins at **200** and in a step **202**, it is determined whether the target is equal to the left son. The "target" is, of course, the client to be deleted. If the target is the left son, a step **204** determines if there are other siblings. If not, the left son is deleted in a step **206**. If there are other siblings, a step **208** makes the next sibling the left son, and then the left son is deleted by step **206**. The process is then completed at **210**. If step **202** determines that the left target is not equal to the left son, the target is found in a step **212**, and is then deleted in a step **214**. A step **216** then changes the sibling pointers, and he process is completed at **210**.

FIGS. **8***a*–**8***c* are several scenarios used to illustrate the process of FIG. **8**. Assume that there is a tree structure as illustrated in FIG. **8***a*. If the node "A" (i.e. a client A) of FIG. **8***a* "disappears" all nodes (clients) **218** that used client A as a path to the server P are dropped from the network as illustrated in FIG. **8***b*. With reference again to FIG. **8***a*, if the node C disappears, the sibling B will simply reset its pointer to point to sibling D without any loss of service to any of the nodes. The lost nodes **218** of FIG. **8***b* will need to re-establish themselves into the network as previously described.

FIG. **9***a* is a tree structure that will be used to illustrate the step **134** "Place Network Tree In Client Transmit Buffer" of FIG. **6**. Since the tree structure **220** is a logical construct, it must be represented in a form suitable for digital transmission. This form is illustrated in FIG. **9***b* as a string **222**. With reference to both FIGS. **9***a* and **9***b*, the string **222** represents the tree on a top-to-bottom, left-to-right basis. Therefore, the string **222** indicates for the parent X that its left son is **3** with a right sibling B. For the parent **3**, there is a left son **9** with a right sibling Z. For the parent Z, there is a left son **8**, a right sibling **5**, and another right sibling Q. For the parent Q, there is a left son P. Therefore, the tree structure **220** has been completely and compactly represented by the notation of the string **222**.

The converting of trees to strings and the reverse is well known to those skilled in the art. In short, a left parenthesis in the string indicates that a left son follows, and a comma in the string indicates that a right sibling follows. For example, the aforementioned book *SNOBOL 4: Techniques and Applications* describe the process for converting trees to

"prefix form" as described above, and vice versa. The aforementioned book *ALGORITHMS IN SNOBOL* 4 likewise describes the process.

While the tree structure **9***a* is useful for representing and traversing a tree data structure, it is not well-adapted for rapid searching for particular nodes. For this purpose, the table of FIG. **9***c* is created to implement fast searching and other housekeeping functions. In this illustration, the table of FIG. **9***c* includes four columns. The first column is the sequential element or "node" number, a second column **226** is the node name, the third column **228** includes the time stamp of the creation of the node, and the fourth column includes the actual physical memory location of the node. In this way, a particular node can be searched by element number, node name, time stamp, or memory location without resorting to the time consuming recursive search algorithms otherwise typically used to search tree structures.

FIG. **10** is a pictorial representation of a portion of the server of FIG. **3** that has been simplified to explain the steps **78** of FIG. **4** "Communicate With Network." The wireless network system **10** includes a number of clients and, perhaps, other servers, each of which has its own IP address. The radio modems of those clients and servers communicate with radio modem **62** of the server which provides digital data to the serial port of a server computer or host **38**. A router, bridge or other device is used to connect the server to a network, such as a TCP/IP network **12**. Of course the radio packet modem **62** and the server computer **38** can be considered part of the wireless network system **10** as described previously. The combination of the server and the router or the like performs a "gateway" function, in that it provides translation services between the two networks **10** and **12**.

Referring back to FIG. **4**, the step **76** "Send Packets" simply involves sending the data packets stored in the client transmit buffer to the network **10** through the radio modem **62**. Likewise, and in a straightforward matter, the step **78** "Communicate With Network" simply forwards the data stored in the network transmit buffer to the network through the router **14** or through another route, such as the Ethernet interface **58**. The "Send Packets" and "Communicate With Network" processes will be easily understood by those skilled in the art. Again, the server process control **72** allocates system resources among the processes **74–80** on a round-robin basis.

In FIG. **11**, the housekeeping process **80** of FIG. **4** is illustrated in greater detail. Since the housekeeping function **80** is of generally less importance than the other functions of process **70**, it is possible that housekeeping function will be interrupted with a branch to one of functions **74**, **76** and **78** of FIG. **4**.

More particularly, in FIG. **11**, the housekeeping function **80** of FIG. **4** is illustrated in greater detail. The process **80** begins at **232** and, in a decision step **234**, it is determined whether a flag is set. If not, the next element is equal to 1, i.e. it is picking the first element on the list. If step **234** determines that a flag is set, the process **80** knows that the housekeeping has been interrupted in the middle of the list and therefore the next element is set equal to the stored mark point as indicated in step **238**. Next, a step **240** determines whether if the end of the table has been reached. If so, the process is completed at **242**. If the end of the table has not been reached, the element retrieved in a step **244**, and then in a step **246**, it is determined whether the current time minus the time stamp is greater than a predetermined interval. If it is, a step **248** deletes the client from the tree and from the table. This step **248** is performed to ensure that a client node that has dropped out the network **10** without informing the server is deleted from the server tree at some point in time. A suitable interval may be 15 minutes, or any desired interval set by a network manager. Process control then returns to step **240**.

If step **246** determines that a node (i.e. a client) corresponding to the next element has checked-in within the time INTERVAL, a step **250** determines whether there is heavy traffic on the server. If not, process control is returned to step **240**. If there is heavy traffic, a step **252** marks the place in the table corresponding to the current element (i.e. the marked point in the list is stored in memory) and then a step **254** determines the traffic type. Process control then branches to process **256** if it is heavy network traffic, **258** if it is heavy outgoing packet traffic, and process **2600** if it is heavy incoming packet traffic.

In FIG. **12**, a radio modem **62** (which can be similar to all of the radio modems described herein) is illustrated in block diagram form. Again, the radio modem **62** is commercially available from GRE America, Inc. as the Gina spread spectrum radio modem, models 6000N-5 or 8000N-5. Spread spectrum technology gives good reliability and some transmission security in that a 127 bit cyclical code must be known by both the transmitting and receiving node. However, for true data security, encryption techniques, well known to those skilled in the art, should be used. Gina modems do include the option of 64 bit built-in encryption as an option.

It should be further noted that the Gina radio modem hardware can be modified to incorporate the server process (or the client process for the client radio modems) of the present invention by storing program steps implementing those processes into a ROM or programmable ROM (PROM) **262** of the radio modem **62**.

The radio modem **262** includes a microprocessor **264** coupled to a bus **268**. The microprocessor is an Intel 80C188 microprocessor in the present example. The PROM **262** (which currently stores 512 Kbytes of code) is coupled to the bus, as is RAM **268**, a serial interface **272**, and an HDLC converter **272**. Coupled to the HDLC **272** interface is a transceiver interface **274**, and coupled to the transceiver interface **274** is a CSMA/CD unit **276**. A transceiver unit **278** with an antenna **280** is coupled to the CSMA/CD unit **276**.

The devices **272** and **276** are used for error correction and noise cancellation, as will be appreciated by those skilled in the art. The CSMA/CD detects if two packets have "collided" producing indecipherable noise. If so, no acknowledgment of the packet is sent by radio modem **62** and the senders of the two packets will wait a short random period before resending their packets. Since the waiting period is random, there is little likelihood that the packets will collide a second time. The HDLC performs a checksum on the received packets and, if the checksum fails, prevents the sending of the acknowledgment. This will cause the sending node to resend the packet after a random waiting period.

The currently used radio modems operate in the 902–928 MHz frequency range at about 725 mW, and have an outdoor range of up to 12 miles, line-of-sight. These characteristics are a good compromise for a light to moderately dense network. If the network becomes very dense, it may be preferable to reduce the power, since this will reduce the number of clients that hear a given packet. Also, other frequency ranges are also suitable, such as the 2.404 to 2.478 GHz range.

The currently sold Gina spread spectrum radio models have their transmission ("baud") rate artificially limited to 38.4 kHz. However, this artificial limit can be easily

removed by a simple change to the program in PROM **262** to allow the modems to operate at 115.2 kHz, or nearly at full ISDN baud rates. At these baud rates, a single server can reasonably support three simultaneous WWW browser sessions and a dozen e-mail sessions. This compares very favorably to cellular networks which, as noted previously, can only support one user at a time. This also compares very favorably to the Ricochet system which, since it is limited to 28.8K baud, is not very useful for WWW browsing.

In FIG. **13**, a client **18** including a computer **20** and a radio modem **22** of FIG. **1** is illustrated in greater detail. Again, the client computer **20** can be any suitable form of digital processor including personal computer, workstation, PDA, etc. A computer **20** includes a microprocessor **282**, RAM **284**, and ROM **286**. The microprocessor is coupled to the RAM **284** and the ROM **286** by a memory bus **288**. The microprocessor **282** is also coupled to an input/output (I/O) bus **290** to which a number of peripherals **292** nay be attached, including the radio modem **22**. As before, the radio modem **22** includes a control C portion and a radio R portion, where the control portion of the radio modem **22** is coupled to the I/O bus **290**. With brief reference to FIG. **12**, the control portion C is everything but the transceiver unit **278** and the antenna **280**, and the radio portion R corresponds to the transceiver unit **278**. Also, as before, the client process running on the client **18** can run on the computer **20**, in the control C portion of the modem **22**, or partially on both processors. The client **18** typically includes other peripherals **297** such as a removable media drive **294** receptive to removable media **296**, (such as a floppy disk or a CD ROM) and to a hard disk drive **298**. Those skilled in the design of computer system will readily understand how the hardware of client **18** is assembled and used.

In alternate embodiments of the present invention, uninterruptible power supplies and Global Positioning Systems (GPS) are added to the clients **18**. The uninterruptible power supplies ensure that the clients stay on the network, and the GPS can be used in conjunction with directional antennas (such as phased array antennas) attached to the radio modems **22** to direct the transmission to the desired next node in the link. This increases the efficiency of the system, and reduces "packet pollution" of the network. The GPS unit can be coupled to I/O bus **290**, or can be incorporated into the radio modem **22**.

In FIG. **14**, a client process **300** is implemented in the hardware of client **18**. Again, this process can run on the microprocessor **282**, or it can be partially or wholly run on the microprocessor of the controller C of the radio modem **22**. In this current preferred embodiment, the process **300** runs on the computer portion **20** of the client **18**. The client process **30** includes a client process control **302**, a process **304** for radio transmitting and receiving data packet, and a process **306** for maintaining a first-in-first-out (FIFO) buffer for send and receive data packets in the RAM **284** of the computer **20**.

In FIG. **15**, the process **304** of FIG. **14** is described in greater detail. The process **304** begins at **308** and, in a step **310**, it is determined whether the client is on the network. If not, the client needs to get on the network before it can send data to the server. This connection process begins at **312** to determine whether it is out of tries in trying to reach the server. If not, it sends a 01 packet in a step **314** and waits to receive a 02 packet from the server or another client in a step **316**. If it does not receive a 02 packet in response to 01 packet, process control is returned to step **312** until it runs out of server tries. When it does run out of server tries, process control is turned over to a step **318** which determines whether it is out of client tries. If yes, this particular client cannot reach either a server or another client and the process terminates at **320** with a failure. If it is not out of client tries in step **318**, a 03 packet is sent in a step **321** and the client waits to receive a 04 from another client in a step **322**. If a 04 is not received, the process control is returned to step **318** until they are out of client tries.

If a 02 is received in a step **316** or a 04 is received in a step **322**, then the client is in communication with the server or a client, respectively. In either instance, a step **324** stores the "link," i.e. the path to a server, whether it is direct to the server or through one or more intermediate clients. Next, in a step **326**, a 05 is sent to the link, and a step **328** determines whether a 06 is returned. If not, the process is terminated as indicated at **320**. If a 06 has been received then a 07 is sent to the link in a step **330** and a step **332** determines whether a 08 is returned. If not, a step **334** determines is they are out of tries, and if not, process control is returned to step **330** to send another 07 to the link. If after a certain number of tries, e.g. 3 tries, a 08 is not received in response to 07 transmitted by the client, the process terminates with a failure at a step **320**. If a 08 is received as determined by step **332**, a random check-in time is set in a step **336**. A random check-in time is set so that not all clients will try to check in with the server at the same time. Preferably, the random times will equally distribute the check-in times for the various clients equally within the aforementioned period INTERVAL. Finally, at this point, the client is connected into the network and the transmit/receive process is accomplished in a step **338**. Of course, if the client was on the network as determined by step **310**, the step **338** can be performed directly. The step **338** will be performed until there is a time-out of the transmit/receive process due to the round-robin scheduling by the client process control **302** (see FIG. **14**).

In FIG. **16**, the process **338** "Perform Transmit/Receive" is illustrated in greater detail. The process **338** has a transmit/receive process control **340** and three subprocesses **342**, **344**, and **346**. Again, the time allocated to the various subprocesses on a round-robin basis.

The subprocess **342** is the check-in routine where the client is required to check in on a periodic basis with the server to avoid being dropped from the server's routing list. As noted previously, the check-in start time is essentially random, and is within a given period INTERVAL. More particularly, the subprocess **342** begins with a decision **348** as to whether it is the proper time to check-in. If not, process control is immediately returned to process control **340**. If it is check-in time, a 07 is sent to the server. If a 08 is received from the server, all is well and process control is returned to process control **340**. If the expected 08 is not received, decision step **354** determines if there are any more tries. Typically, at least three tries will be allowed. If there are more tries, process control is returned to step **350**. If there aren't any more tries, a step **356** will authenticate and send an **11** to the left son of the client that the client is removing itself from the network. Authentication prevents the situation where a "promiscuous" spooler could masquerade as a client and transmit an "11" packet with downstream client addresses, thereby disconnecting those downstream clients from the network. The client then marks itself as being disconnected or "off" of the network in a step **358**, and process control is returned to process control **340**.

In FIG. **17**, the process **344** "Process Computer Received Packets" is shown in flow diagram form. The process **344** begins at **360** and, in a step **362**, the data is obtained from a buffer. Next, in a step **364**, the header is added to the data including the link and the packet type "14" to indicate that

this is a data-type data packet. Next, the data packet, complete with header, is transmitted in a step **366** and the process is completed at **368**.

FIG. **18** illustrates the process **346** "Process Radio Received Packets" of FIG. **16** in greater detail. The process **346** begins at **370** and, in a step **373**, determines if the received packet is for it. If yes, a step **374** will process the packet per the code type, as will be discussed in greater detail subsequently. Then, a step **376** determines if the father node of the client has been marked. If not, a new, shorter link is created since the packet was received without being relayed by the father node. If the father node has been marked, or after a new link has been created, the process terminates at **380**.

If step **372** determines that it is not that client's packet, a step **382** determines if that client is on the route for the packet. If yes, a step **384** tests to see if the client is marked. If it is marked, it has already sent that packet and the process is completed at **380**. If the client hasn't been marked, it marks itself in the header of the data packet and transmits the packet in a step **386**. Process control is then given to step **376** to see if the client's link can be upgraded as discussed previously.

If step **382** determines that the packet is not for that client, and that the client is not part of the link, steps **388**–**392** still analyze the packet in a process known as "pooning." Since this client can hear this packet, there is an opportunity to upgrade its link. Step **388** determines whether the link to the last marked node plus one (i.e. the distance to the first unmarked node) is shorter than its own link. This is because this client is listening to the last marked node, and the number of hops through that last marked node is the number of hops of that last marked node plus one. If it is, the client's link is updated in a step **392** to this shorter link. If not, the alternative route is cached in case the client's current link becomes inoperative. Therefore, in the pooning process, the client listens to all packets to continuously and dynamically update its link to the best possible path.

In FIG. **18**A, a data packet **394** of the present invention includes a header portion **396** including a link section **398** and a data type section **400**, and a data portion **402**. The link **398** indicates that the destination of this data packet is the node P. The two digit data type **400** indicates what type of data is being sent, and the data field **402** includes the actual data and is terminated within EOD (end of data) marker. This packet corresponds to the tree of FIG. **9***a*. Since all upstream nodes (i.e. nodes Q, Z, **3**, and X) are marked with asterisks ("*"), it is known that the data packet has passed through and has been marked by each of these nodes before reaching the node P. If, however, the data packet **394'** of FIG. **18**B is received where in only nodes X and **3** are marked, this means that the node **3** can hear the transmission of node (client) **3** directly. In this instance, there is no need to go through nodes Q and Z to reach the server X. As a result, the new, upgraded link is from node P to node **3** to the server X. This is represented by the notation:

X(3((P)).

The table of FIG. **19** is used to illustrate the "Process Per Type Code" step **384** of FIG. **18**. The table of FIG. **19** includes three columns **404**, **406**, and **408**. The first column **404**, lists the codes that can be received. These codes corresponds to the 2 byte code **400** of the data packet **394** of FIG. **18**A. The second column **406** corresponds to the server responses to receiving such codes, and the third column **408** are the client responses to receiving the codes. We will now discuss each of the codes, in sequence.

When the server receives a 01 code, its response is a 02 code plus a one-way seed as discussed previously. Since a 01 code is never intended for a client, it will ignore or "drop" the 01 coded data packets.

For the 02, 03, and 04 codes, the server will ignore or drop those data packets because these data packets are only intended for clients. If a client receives a 02, it responds with a 05 and a one-way response. In response to a 03, a client will send a 04 and a seed or a null. In response to a 04, the client will send a 05 and a one-way seed. Again, one-way seeds and responses to one-way seeds were discussed previously.

When a server receives a 05, if it has previously sent a 02 and if the 05 is authentic, then it will send a 06. Otherwise, it will drop the packet. When a client receives a 05, if it had previously sent a 04, and if the 05 is authentic, then it sends a 06. Otherwise, the client will drop the data packet. If the server receives a 06, it will drop the data packet. If a client receives a 06 after it sent a 05, then it will send a 07. Otherwise, it will drop the packet as well.

When a 07 is received from the server, it will immediately respond with a 08. Since 07 coded packets are never intended for clients, it will be dropped.

Data packets coded with an 08, 09, 10, or 11 are all dropped if received by a server. If a client receives a 08, it will update the tree or repeat the data. In response to a 09, a client will send a 10. In response to a 10, a client will update the tree or repeat the data. In response to a type 11, it send an 11 to the left son with the address the departing node plus a 01 to reconnect to the network.

Data packets of type **12** and **86** are currently reserved. In response to a data packet type **13**, a server will delete the sender. Since this is a server destination data packet only, if a client receives a data packet of type **13**, it will drop the data packet.

Finally, if a server receives a data packet of type **14**, it will send it to the network transmit buffer. If a client receives a data packet of type **14**, it will send it to the computer transmit buffer.

FIG. **20** illustrates an initialization routine which connects a client CB to a server S through another client CA. The sequence is as follows. As indicated by arrow a, client CB sends a 03 to client CA. In return, the client CA sends a 04 and a seed back to client CB as indicated by arrow b. Client CB then sends a 05 and a one-way response as indicated by arrow c to client CA, and client CA sends a 06 and an acknowledgment with a 05 to client CD as indicated by arrow d. Then, client CB sends a 09 to client CA as indicated by arrow e, and client CA sends a 10 and the link to the client CB as indicated by arrow f. Client CB then sends a 07 and the neighbor's addresses to the client CA as indicated by arrow g, and a client CA relays the 07 and the neighbor's address to the server S as indicated by arrow g'. The server S then sends a 08 and the tree to the client CA as indicated by arrow h, and the client CA relays the 08 and the tree to the client CB as indicated by the arrow h'. At this point, the client CB has the link to the server S and the complete tree of the network in its memory.

FIGS. **21***a*–**21***d* illustrate a portion of the server process which deals with determining a return path from a received data packet at a server. Assume, for example, the tree is known to the server is as illustrated in FIG. **21***a*. This is the same tree as was illustrated in an example of FIGS. **9***a* and **9***b*. Then, assume that the server X receives the packet from a client P as illustrated in FIG. **21***b*. The simplest way of determining the reverse address is simply reverse the link section of the header portion of the data packet of FIG. **21***b*

to provide a return address of **21***c*. However, if the part of the address of the header of the data packet of FIG. **21***b* has been lost or corrupted during the transition process, the tree of FIG. **21***a* can be used to reconstruct the return path. This is accomplished by jumping from parent to parent in reverse order as indicated to determine the return path. In this example, the reverse order parent jumping indicates that the original path the server X was P>Q>Z>**3** >X, which, when reversed, gives us the proper reverse path, namely X(**3**(Z(Q(P)))). As will be appreciated by those skilled in the art, this type of reverse tree traversal is easily accomplished with a recursive function.

While this invention has been described in terms of several preferred embodiments, there are alterations, permutations, and equivalents which fall within the scope of this invention. It should also be noted that there are may alternative ways of implementing both the process and apparatus of the present invention. It is therefore intended that the following appended claims be interpreted as including all such alterations, permutations, and equivalents as fall within the true spirit and scope of the present invention.

What is claimed is:

1. A wireless network system comprising:

a wireless router client operable for broadcast communication with at least one wireless router server and at least one additional client, said server including a digital controller operably coupled to a server wireless interface operable to broadcast and receive data packets in the wireless network;

said server digital controller further including a server program operable for determining an optimal route from the server to the client through at least one additional client if a direct one-hop route is not available;

said client including a client digital controller operably connected to a client wireless interface and operable to a broadcast and receive data packets in the wireless network;

said client digital controller further including a client program comprising instructions for determining an optimal route from the client to the server via an indirect multi-hop route through at least one additional client if a direct one hop route is not available; instructions for determining if a received data packet is not addressed to the client; and if so instructions for analyzing a data packet to determine if the data packet has been sent on a new optimal route unknown to the client and for notifying the server through the interfaces and the wireless network of the new optimal route;

said server program and said client program operable together via parallel processing to determine a new optimal route by exchanging in-memory routing tree link information;

said server updating its internal memory routing tree link information with the new optimal route information.

2. The network of claim **1**, wherein the client program further comprises instruction operable to analyze the received data packet and control the client to rebroadcast the data packet on behalf of the originating client if the client is on the received data packet's optimal route to the server.

3. The network of claim **2**, wherein the client program further comprises instructions operable to inhibit said re-broadcast of the data packet if the client has previously re-broadcast this data packet.

4. The network of claim **1**, wherein said server program is operable for determining the optimal route via an indirect multi-hop route through the at least one additional client if a direct one-hop route is not available, and the server program and client program are operable together via parallel processing to determine the optimal route by exchanging in-memory routing tree link information.

5. The network of claim **1**, wherein the server program and the client program parallel processing is further operable such that the optimal route between the client and the server is computed with possible mediation by other clients by means of converting an extant in-memory tree maintained by the server into a prefix string notation for (a) broadcast through client wireless interfaces of only those clients on the optimal route between the sever and target client, and (b) reception by the target client for conversion from the prefix string notation into said in-memory.

6. The network of claim **1**, wherein the server program and the client program parallel processing is further operable to add a header to the data packet that includes the data transmission link information for the data packet and the data type of the data packet when the client initiated broadcasting the data packet.

7. The network of claim **1**, wherein the client program further comprises instructions operable to analyze data packets received by the client wireless interface to determine whether there is a new optimal link of fewer hops to the server than said optimal route, and, if so, to update the client's in-memory routing tree link information based on the determined new optimal link.

8. The network of claim **1**, wherein the client program further comprises instructions operable to analyze said received data packet by; (i) counting the number of hops between the packet's originating client and the server; and (ii) counting the number of hops between the packet's originating client and the client; and when the sum of said hops is fewer than the number of hops of the extant link between the client and the server, (a) abandoning the extant link and removing it from the client's in-memory routing tree link information , (b) refreshing the client's in-memory routing tree link information with the new link, and (c) notifying and updating through the wireless interfaces and the wireless network the in-memory routing tree link information of the server.

9. The network of claim **1**, wherein the client program further comprises instructions operable to choose said new optimal route to the server from the group consisting essentially of the link to the server through (a) the least possible number of additional clients, (b) the most robust additional clients, (c) client(s) with the least amount packet traffic, and (d) the fastest clients.

10. The network of claim **9**, wherein the client program further comprises instruction operable such that reception of a data packet containing a type field having a value of 08 is the means by which the client remains aware of the survival of its optimal route to the server.

11. The network of claim **1**, wherein the client program further comprises instructions operable when receiving said data packet to determine whether there is a better link to said server, and if so, to update the client TCP/IP routing table, such that in said routing table, the content of a default gateway of the client is updated to be a TCP/IP address of the next-hop router en route to the server.

12. The network of claim **1**, wherein the server program further comprises instructions operable to receive data packets from said client and (a) analyze the data packet, (b) maintain an in-memory tree of the extant links between the server and each and every individual client, and (c) update the server's TCP/IP routing tables to as to add a network TCP/IP address of an Ethernet LAN address of each and every client in said wireless network with which the server also maintains a link within its in-memory tree.

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